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EXTENSION BULLETIN No. 15

the AGRO-CLIMATOLOGY of North Dakota

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part 1/ AIR TEMPERATURE AND GROWING DEGREE DAYS

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The cliché that "everyone talks about the weather but no one does anything about it" has been used for many decades. However, as one becomes more knowledgeable about the general business of agriculture, one recognizes that the subject of agroclimatology may provide links to render this cliché to the realm of oblivion.

Certainly, the four-part series of agroclimatology, presented by Dr. Ramirez and his colleagues, has initiated an area of activity at North Dakota State University which doubtless will provide an insight into many environmental matters so essential to producing agricultural income in North Dakota. Prudent use of the resources of rain, soil and sunlight which help govern the economic success of agriculture, are particularly important to those who, through management and application of exisiting knowledge, endeavor to supply the renewable resources associated with plant life and animal life that provide the backbone of the economy of the Upper Great Plains region.

It is my pleasure to present these brief introductory comments in the first of a series of four publications concerned with climate and agriculture in North Dakota.

KENNETH A. GILLES
Vice President for Agriculture

THE AGROCLIMATOLOGY OF NORTH DAKOTA

Part I. Air Temperatures and Growing Degree Days

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Introduction: Climate and Agriculture in North Dakota

The influence exercised by weather and climate in crop production has been well recognized. Problems associated with agricultural practices such as time of planting, fertilizer application, dusting and spraying, harvesting, irrigation and variety selection can be solved best when properly guided by a thorough knowledge of the limits set by the climatic environment.

To stress the great limiting controls offered by our climatic environment to crop production, one might look at the proportions of all Federal Crop Insurance indemnities paid during the period 1948 through 1963 in North Dakota (Figure 1).

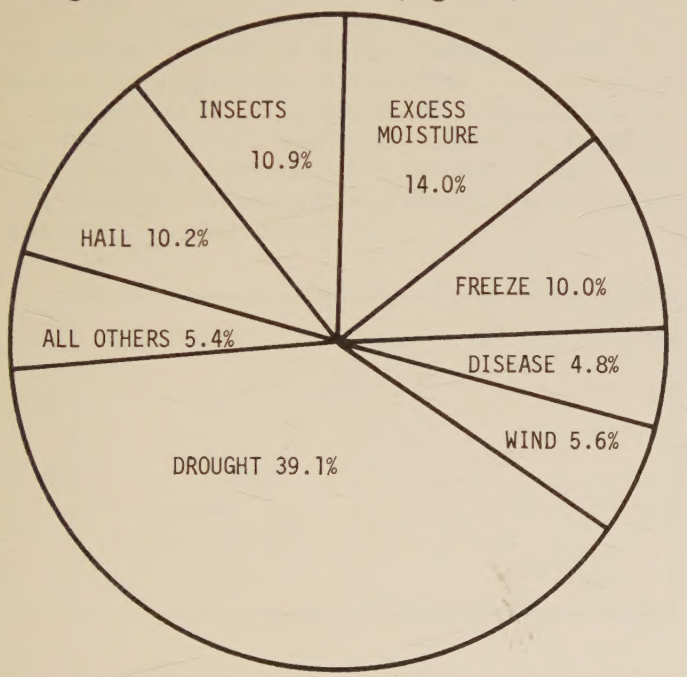


Figure 1. Proportions of all federal crop insurance indemnities paid in North Dakota for various hazards, 1948-63.[1]

Even assuming that incidences of insects, diseases and other hazards are not weather sensitive (which, of course, is not true), the damage due to excess moisture, drought, hail, freeze and wind comprise just a little less than 80 per cent of all hazards faced by farmers for which they received insurance benefits.

[1] From: Delvo, H. W. An Economic Appraisal of All-Risk Crop Insurance in North Dakota, unpublished M.S. Thesis, Dept. of Agric. Econ., NDSU, 1965.

Climatological descriptions, to be most useful, should not be limited simply to means and norms of weather elements, but more importantly, they should include the chances or probabilities of those climatic elements occurring that are particularly critical to crop production. Such descriptions will better serve as valuable guides to farmers in determining the risks involved in their many weather-sensitive operations.

The Department of Soils of the North Dakota State University Agricultural Experiment Station has, for a number of years, been accumulating and organizing daily climatic data on computer magnetic tapes for ease in handling and analyses. These data extend as far back as 1895 and continually are being updated. These constitute a reservoir of information of great value to agriculture when appropriately organized and interpreted to provide bases for strengthening crop production and management decisions.

This is the first of a projected series of four publications on the climatic environment as it affects agriculture in North Dakota. This series is an attempt to organize the long-term climatic data from more than 200 observing stations in the state into a form more directly applicable to management decision-making processes in agribusiness.

The author and future co-authors in this venture plan to include in this series of publications extensive discussions of the climatology of the following:

Part I Air Temperatures and Growing Degree Days

Part II Precipitation: Forecast and Probabilities

Part III Drought and Wet Spell Occurrences

Part IV Severe Storms and Lesser Disturbances: Influence on Agricultural Production

This continuing effort is part of regional project NC-94: The Climatic Resource of the North Central Region. Throughout the progress of this study, consultations with experts from various disciplines in agribusiness are being solicited. Their advice and assistance in interpretation will be helpful in defining applications of the agro-climatic analyses.

PART I. AIR TEMPERATURE AND GROWING DEGREE DAYS

A. AIR TEMPERATURE: NATURE AND INFLUENCES

Temperature Influence in Agriculture

Regardless of how favorable moisture and soil fertility conditions may be, plant growth ceases when air temperature falls below a certain minimum or exceeds a certain maximum value. Between these limits plant performance varies with temperature variations during the growing season as these variations affect soil moisture loss, soil and plant temperatures, and consequently the plant growth processes that determine crop yield. Air temperature on many occasions is either above or below limits tolerated by crops. These limits, as they are in the continental climate of North Dakota, dictate the shorter growing season in the state.

The effects of air temperature in agriculture are not limited to plant response. Decision-making on time of agribusiness operations such as tillage, seeding, spraying, harvesting, crop drying and storage is affected by air temperatures.

Factors Affecting Air Temperatures

The Sun

Life on earth ultimately depends on the sun. It not only produces the weather that shapes our environment, but it also provides the heat energy required by virtually all living things on earth. In spite of its importance to us, the sun in our universe is by no means unique. Among billions of stars in our galaxy, it is average in mass but below average in size, and our galaxy is only one among billions of galaxies. The sun's special importance results from its closeness to us. It is 93 million miles away from earth, while the next closest star is 30,000 times as far away. In spite of its distance, the sun, nevertheless, is such a tremendous power plant that it continually inundates the earth with billions of horse power in the form of heat. About one-third of the energy reaching the earth is reflected and lost back

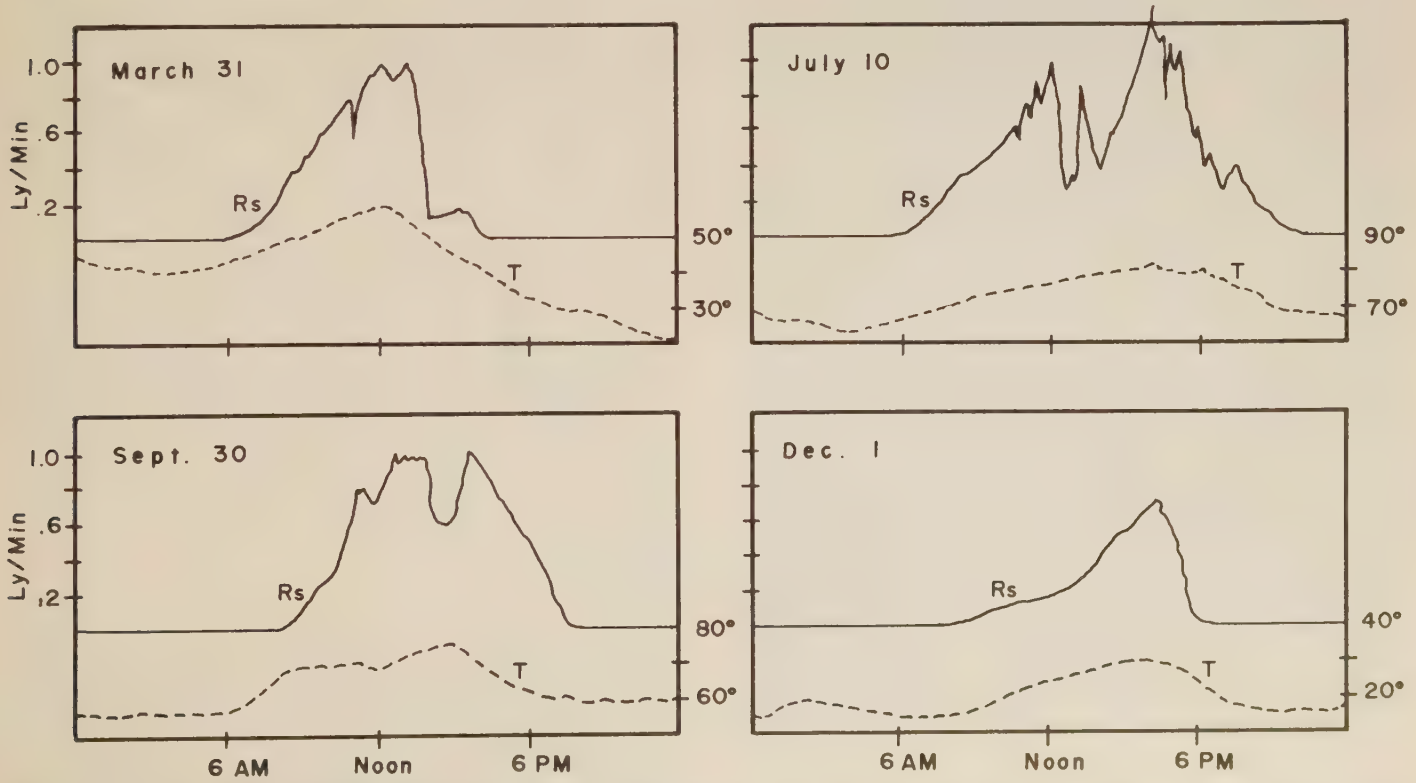


Figure 2. Daily march of solar radiation and air temperature on four selected days at Fargo, North Dakota, 1971.

to space while the remainder is absorbed by the earth and its atmosphere to warm the air, assist in weathermaking, and provide the heat energy necessary for virtually all life processes on earth.

The balance between the incoming sunlight and the outgoing radiant energy from the earth is the primary influence on the daily and seasonal variations of air temperature. Figure 2 illustrates the close dependence of air temperature variations on the patterns of solar radiation. Air temperature lag with respect to sunlight is explained by the fact that it takes time for air to be heated.

Clouds and Other Factors

Air temperature is subject to many other influences. Clouds, acting both as reflectors and absorbers of radiant energy, interfere with both incoming and outgoing radiation. Day-to-day changes in weather patterns, the movement of air masses, both warm and cold, for example, can change the normal daily temperature trends.

Measurement of Air Temperature

Standard measurements of air temperatures made by the National Weather Service and its cooperative observers are usually made in terms of the highest and lowest temperatures during the 24-hour day. The maximum and minimum thermometers used are protected from direct exposure to radiation from the sun or earth. The thermometers are protected by putting them in a special shelter, louvered on all sides for ventilation and which has a double roof for further protection from the sun's rays (Figure 3). The shelter is painted white to reflect most of the solar radiation incident on the box. It is exposed at a standard height of about five feet above the ground. At this level, air temperature fluctuations are minimal when compared to the air layers closer to the ground surface.

Figure 3. Standard maximum and minimum thermometers in an instrument shelter.

Sources of Temperature Data

Air temperature observations made by the National Weather Service are summarized and published in formats displaying the geographical distribution of average temperature, average daily high and low temperatures. Examples of such summaries for North Dakota are those prepared by the National Oceanic and Atmospheric Administration (4, 5). These summaries cover only a description of averages and extremes of temperatures over the state. A recent publication, sponsored by the North Dakota State Water Commission and the North Dakota State University, also includes a general description of extreme and average temperatures around the state (7). Few publications are available on the likelihood of certain temperature values critical to agriculture. In many cases, such presentations cover only the distribution of the first or the last occurrence of frost during the year (16).

The daily climatological data from the more than 200 climatic stations maintained by the National Weather Service have been transcribed onto computer magnetic tape by the Department of Soils. From these stations, 35 were selected for this study according to their length, quality of records and geographical location in the state. The location of the climatic stations selected and used in the computer analyses are shown in Figure 4.

Air Temperatures in North Dakota: A General Summary

The general description of average and extreme air temperatures in North Dakota will be used only as a brief introduction in this publication. The major objective of this bulletin is to show the geographic and seasonal distribution of critically high and favorable temperature conditions over extended periods and describe the probability of their occurrence over the state.

Seasonal Trends

Annual mean temperatures range from about 37° F increasing southward to about 43° F. (Figure 5). Jensen (7) indicated that January is the coldest month with average temperatures ranging from 2° F in the northeast to 17° F in the southwest portion of the state. July is the warmest month with temperatures averaging 67° F in the northeast to 73° F in

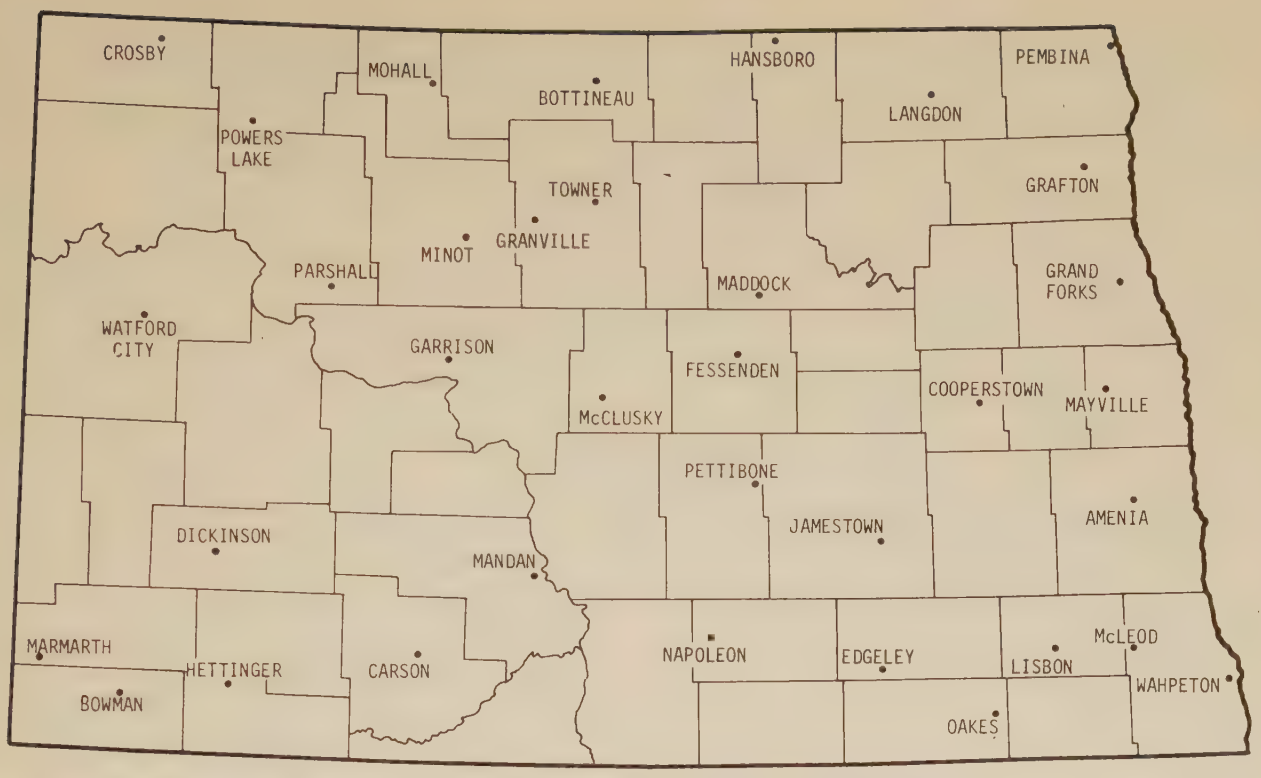


Figure 4. The location of the climatological stations used in the temperature analyses.

the south. North Dakota's climate shows large annual ranges of monthly air temperatures. The difference between the mean temperatures of the warmest and coldest months is 54° F in the southwest to as large as 65° F in the northeast (7).

This large annual range in temperatures is probably best illustrated when one considers that the lowest temperature ever recorded in North Dakota was -60° F (Parshall; February 15, 1936), while the highest recorded was in the same year, 121° F (Steele; July 6, 1936).

Jensen (7) pointed out that the observed variations in the temperature patterns around the state followed the differences in terrain elevations. Although no defined cold air pockets induced by terrain differences may be seen in the annual map of mean temperatures, temperature summaries during shorter periods show cold temperature troughs created by cold air drainage to lower elevations.

Frost-Free Period

On the average, the last day of freeze in the spring (32° F or lower) is May 15 in the southeast to about the end of May in small scattered areas in the northern half of the state. In the fall, the first freeze can be expected on the average between September 15 through 25 over most of the state (7). The average length of frost-free period in North Dakota has been summarized by Sanderson (16). A revised map display of this summary is shown in Figure 6.

The length of the frost-free period, although a reasonable approximation of the length of growing season, is based on temperatures observed in shelters exposed five feet above the ground level. It is not unusual that air temperatures closer to the ground and within plant canopies could be 3° to 7° F lower than those measured inside an instrument shelter. This is particularly true on clear and calm nights and in early morning when radiation loss from soil and crops surfaces is unimpeded by clouds.

B. AIR TEMPERATURE PROBABILITIES

GROWING SEASON TEMPERATURES

The time for planting crops is chosen so that growth, development and harvest closely correspond to seasonal climatic patterns most favorable for yield and quality. In North Dakota, with the exception of some fall-seeded small grains and forages, agronomic crops are seeded in spring as soon as moisture and temperature conditions are favorable for field operations of machinery and when temperatures are warm enough to induce seed germination and sustain early seedling growth.

Crops like oats, sugarbeets and others which germinate at relatively low soil temperatures and

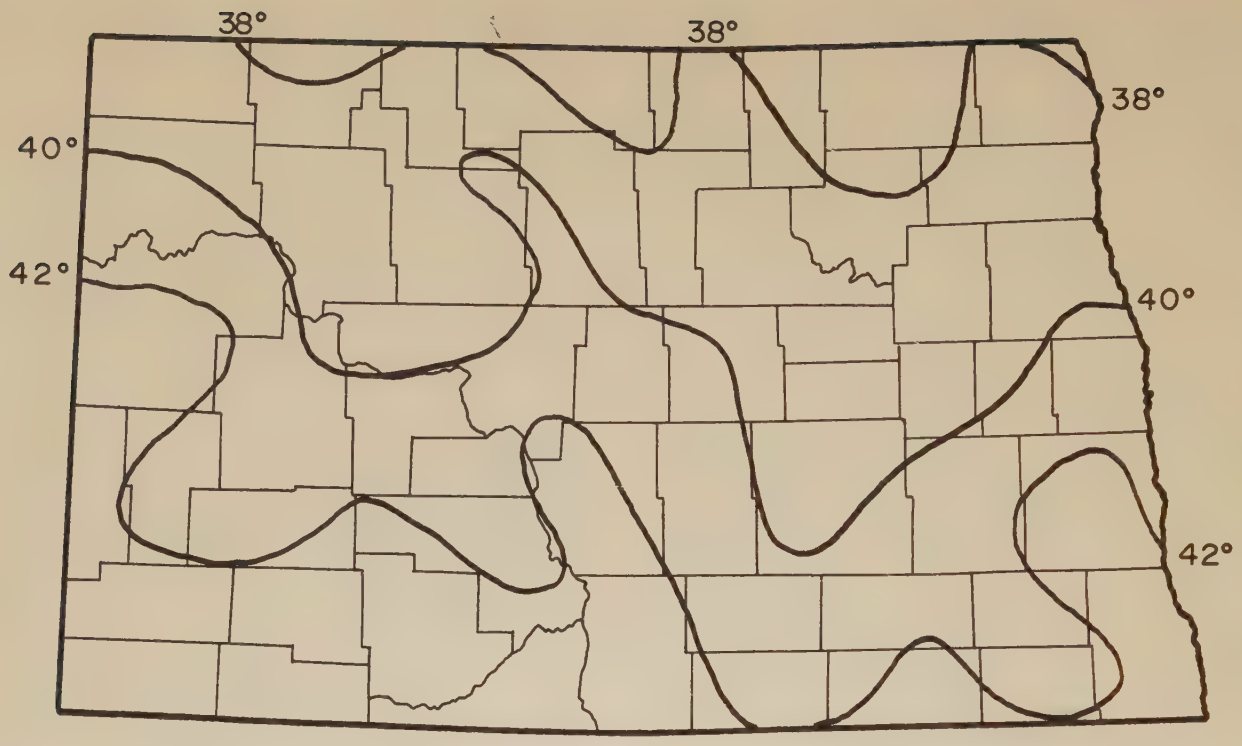


Figure 5. Annual mean temperatures in North Dakota (After Jensen, 7).

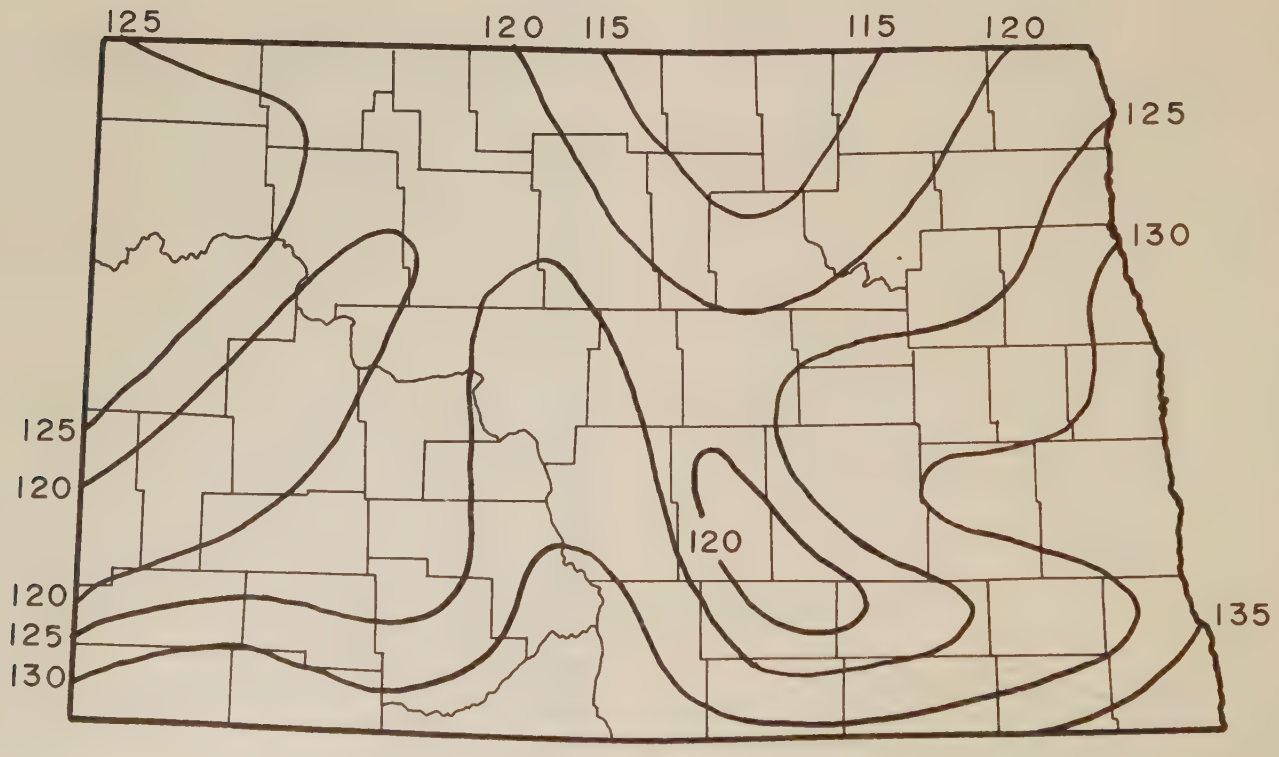
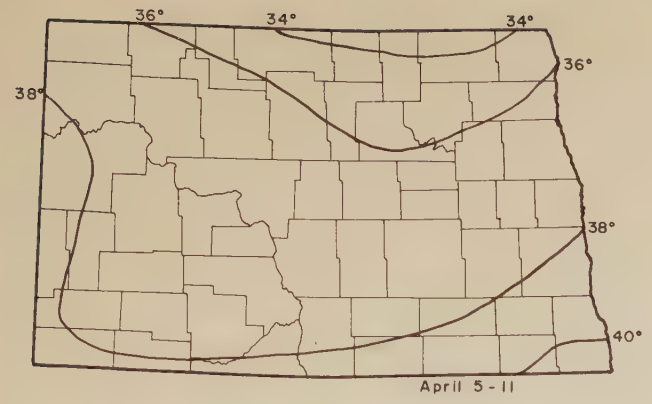
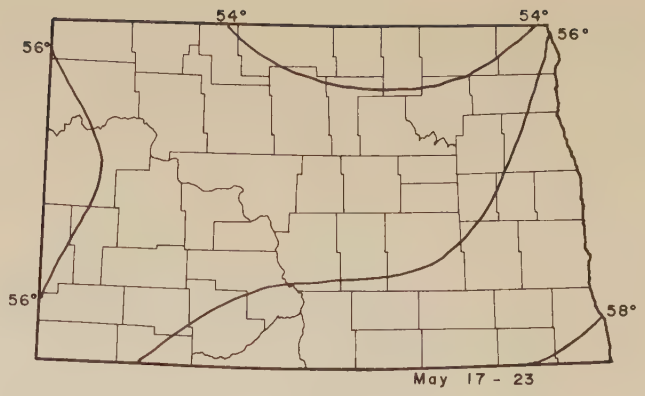
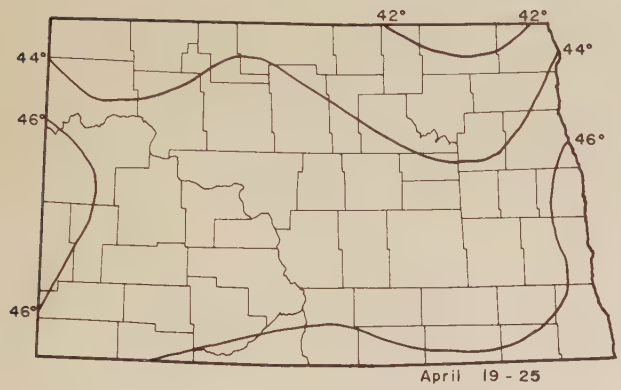
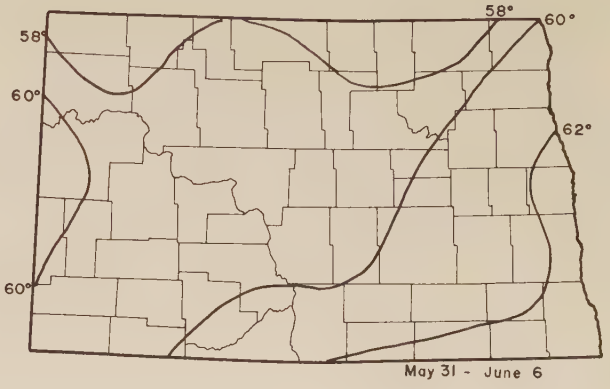


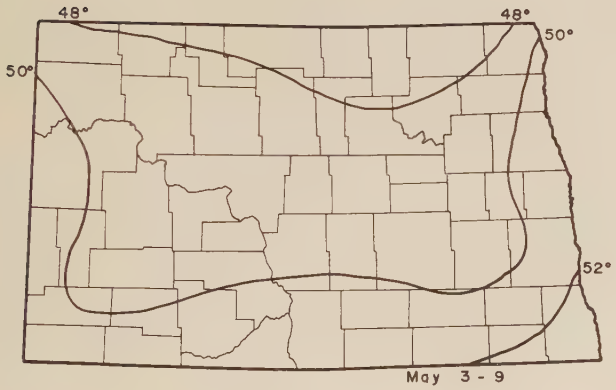
Figure 6. Average length, in days, of freeze-free periods.

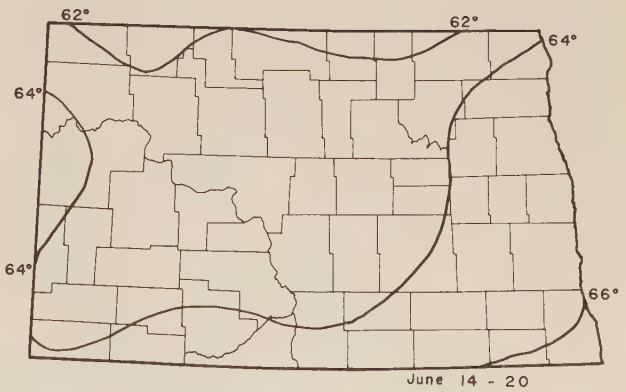












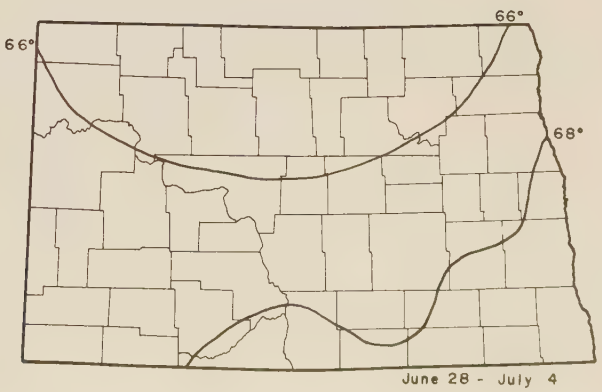
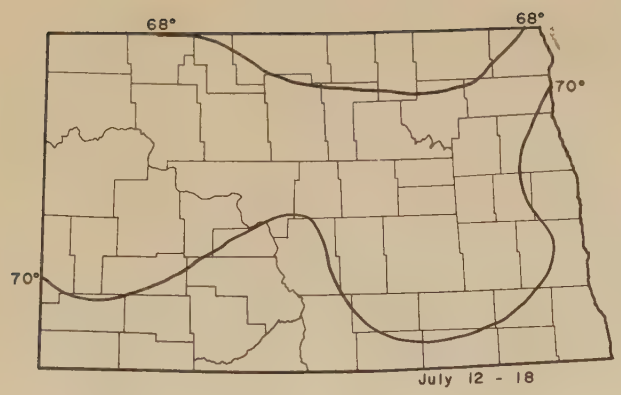
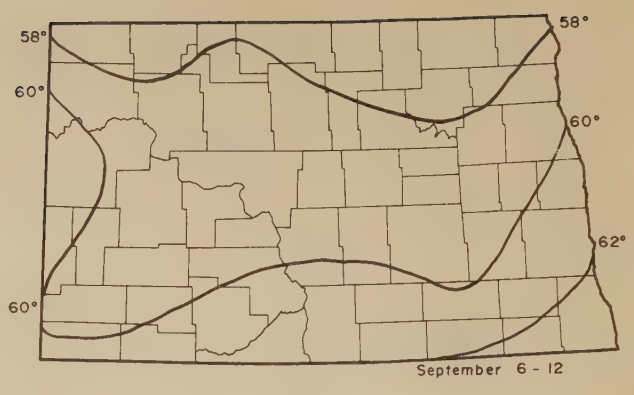


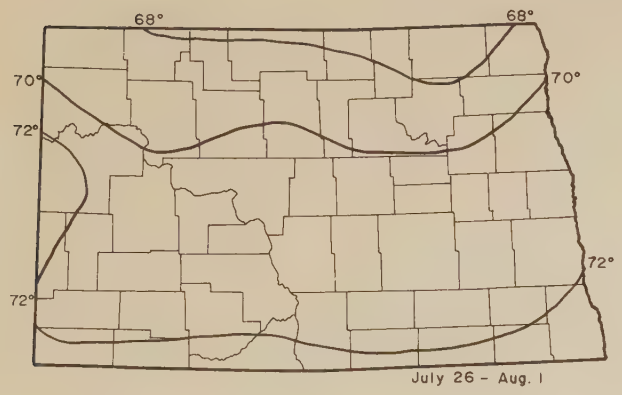
Figure 7. The average weekly temperatures at two-week intervals from April to October across North Dakota.



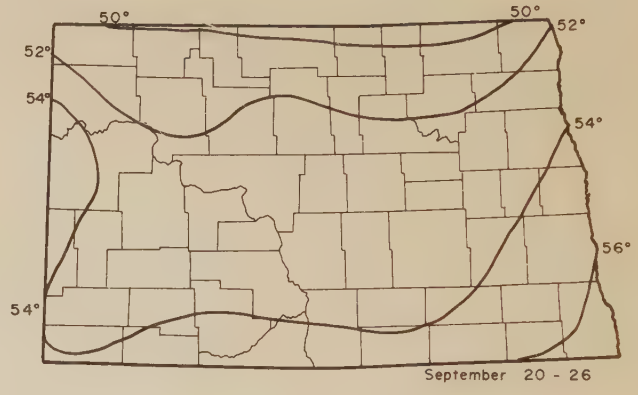
July 12 - 18



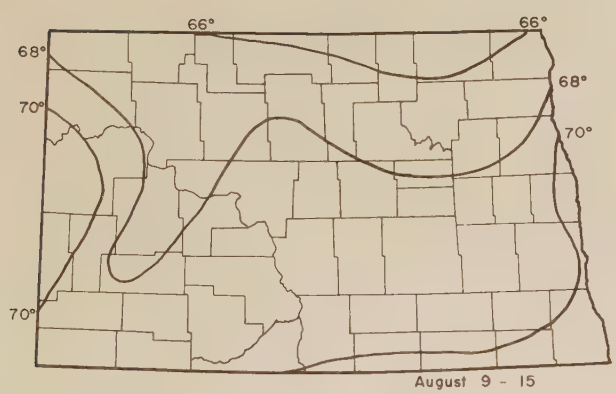
September 6 - 12



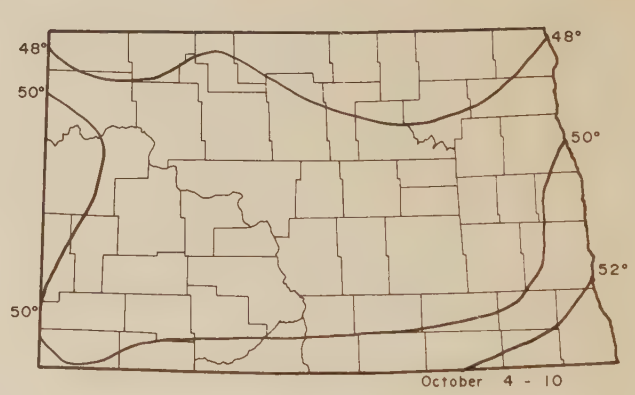
July 26 - Aug. 1



September 20 - 26



August 9 - 15



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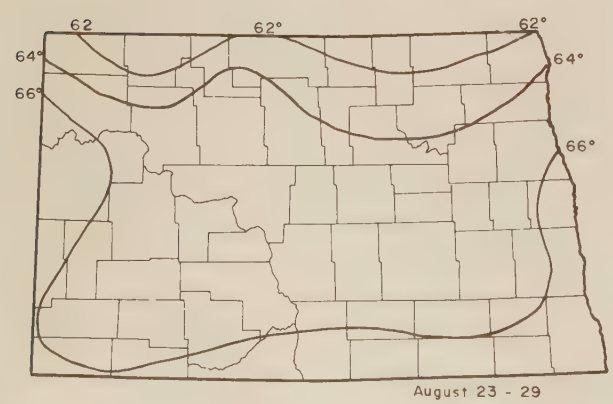
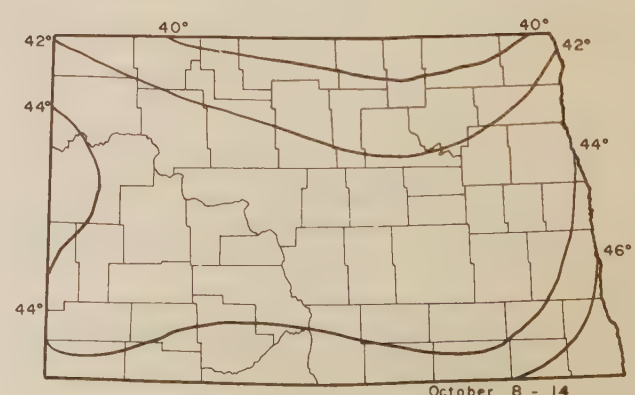


August 23 - 29



October 8 - 14

which are more tolerant to frosts are usually the earliest crops planted while warmer season crops are planted later in the spring as temperatures increase. Jensen and Lund (6) cited that wheat, barley, oats and rye require soil temperatures of at least 34° - 36° F for germination while corn, sorghum and millet seeds require at least 48° - 50° F. There is a very high correlation between soil and air temperatures as one may expect. Baker and Swan (1) showed that this is particularly true in spring right after the soil thaws. For this reason and since soil temperature data that afford in-depth analyses of its distribution across the state are very meager, the air temperature analyses presented in this publication may be used as a guide in scheduling time of planting. The march of average weekly air temperatures across the state from April through October is shown in Figure 7. The period chosen covers the dates when average air temperatures are 40° F and above in at least one location in the state. This temperature is recognized as the base temperature for wheat, barley and rye (11, 12, 13). All locations in the state have at least 40° F average temperature from the third week in April until about the second week in October.

The mean weekly temperatures become progressively higher from 40° F in April up to 72° in mid-August, and then start cooling off again after that date. Throughout the summer, temperatures consistently become higher as one goes southward. There is about a 6-8° F difference in average temperatures between the southernmost and northernmost areas of the state at any one time during the summer.

The maps shown in Figure 7 show each two-week interval. To find the average temperature for the weeks not shown at any one location in the state, visually interpolate from the figures given for the immediate weeks shown. For example, to estimate the mean weekly temperature in the Bottineau area during the week of August 2 through 8, find the figure for July 26 through August 1 (68° F) and that for August 9-15 (66° F) and the average of the two (67° F) will be a close estimate for the week between.

Threshold Temperatures for Spring Planting

The time for seeding agronomic and horticultural crops in North Dakota is subject to critical temperature requirements for seed germination, and the variety tolerance of young seedlings to frost and chilling injuries. From an extensive survey of the northern Great Plains agriculture and its agroclimatically similar regions in other parts of the world, Nuttonson (11, 12, 13) reported that the date of sowing spring wheat, spring rye and barley in the Northern Plains is as early in the spring as when the soil can be worked into a seedbed. He pointed out that this date corresponds to a period when the mean daily air temperature is about 40° F and higher.

Neild (10) reported that the beginning of oats seeding is usually when average temperatures first rise to 43°F; early potatoes, 45° F; and corn, 55° F. Such warm season crops as snap-beans require temperatures in the upper 50's to the lower 60's (10, 14).

Since these critical temperatures vary for different crops, the probabilities of weekly average threshold values of 40° and 50° F were calculated for different weeks of the "planting season", March 8 through June 13. Results are shown in Figures 8 and 9. These maps can be used to determine the likelihood that air temperatures will be warm enough after a planting date to sustain young seedling growth of various crops. The maps shown are only those for weeks when the probability lines of 10 per cent through 90 per cent may be drawn.

To illustrate the practical use of these maps, let us assume that temperatures should average higher than 50° to sustain newly emerging potato plants on a farm near Grafton. What are the chances of such favorable conditions in April and May? The following set of maps show that the probabilities for each week are:

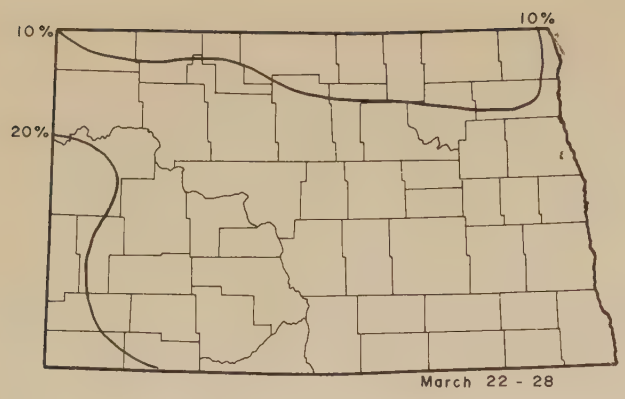
April 5 to 11—near 0 per cent
April 12 to 18—less than 10 per cent
April 19 to 25—less than 20 per cent
April 26 to May 2—40 per cent
May 3 to 9—40 per cent
May 10 to 16—60 per cent
May 17 to 23—more than 90 per cent
May 24 to 30—close to 100 per cent

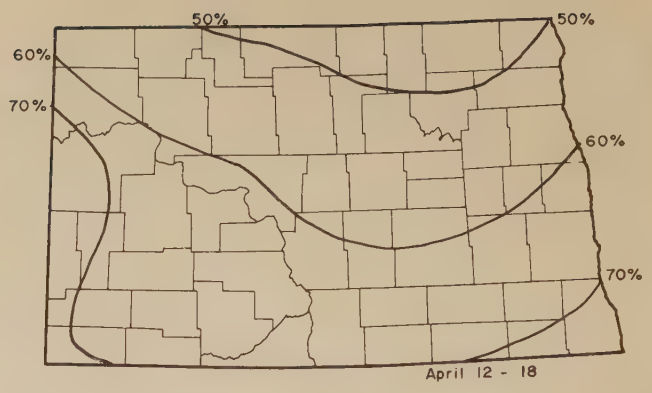
From the above figures, a farmer near Grafton looking for an average of at least 50° F before planting potatoes has better than a 50-50 chance after about the first week in May. From that date on, his final decision rests on how much risk he wishes to take and by other management factors.

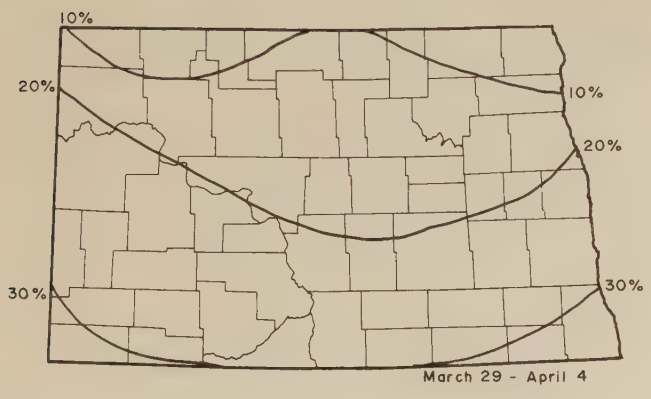
Over most of North Dakota, it is not until about mid-April that there is a better than 50 per cent chance that average temperatures will be at least 40° F, and it is not until a month later that it will be at least 50° F. Considering these figures, it is not surprising that cool season crops are started in the state around April 15 on the average and warmer season crops and vegetables usually are not started until about the middle of May.

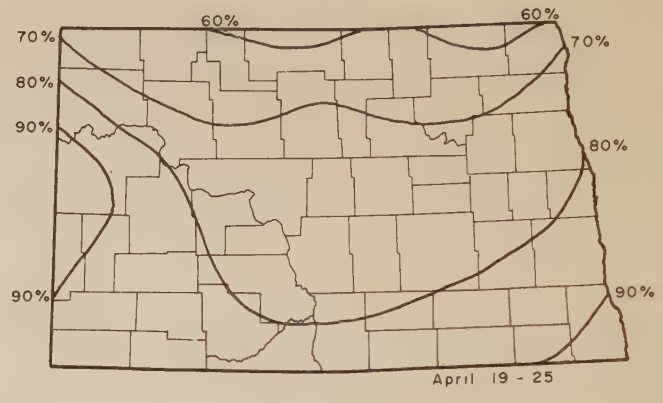
Temperature Risks Involved in Late Planting

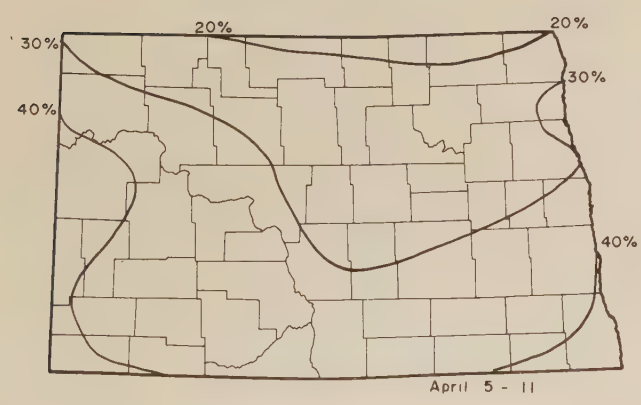
Besides problems of weeds and unfavorable soil moisture conditions for young crop growth later in mid-summer, farmers who are forced to plant later in the spring due to availability of labor and moisture conditions have added risks with which to contend. Nuttonson (11, 12, 13) reported that spring va-











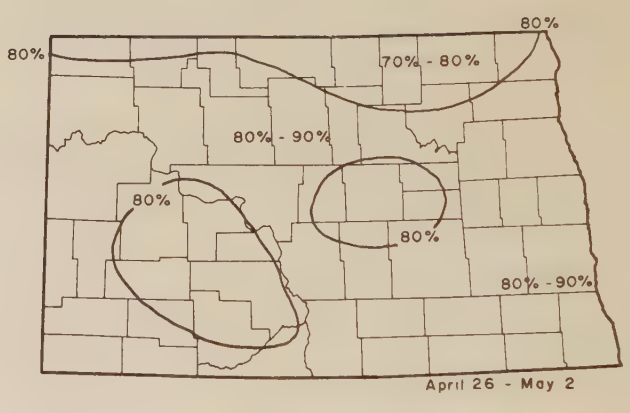


Figure 8. The probabilities that the average weekly temperatures will be 40° and higher during the spring planing season.

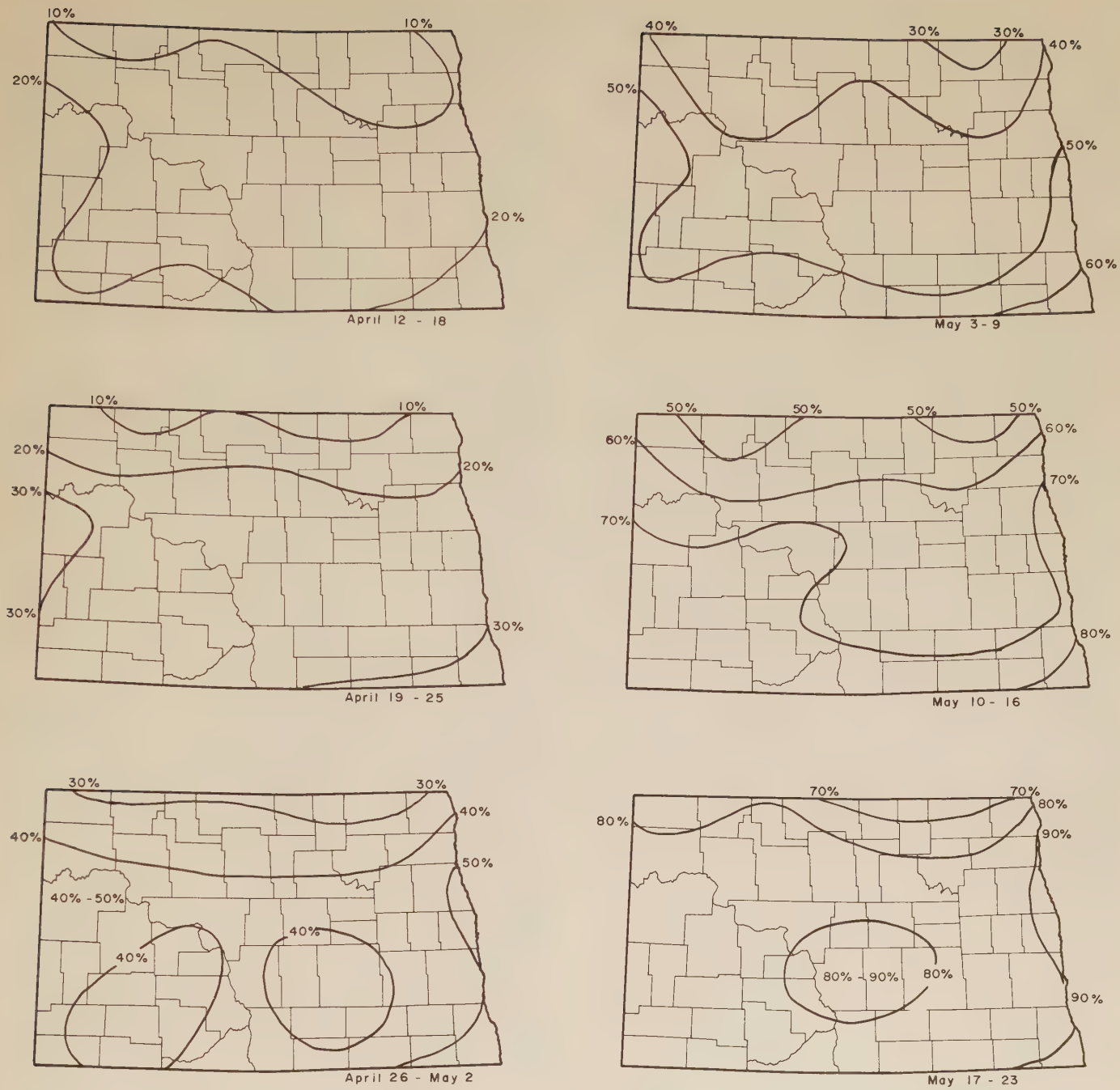


Figure 9. The probabilities that the average weekly temperatures will be 50° and higher during the spring planting season.

Table 1. The dates of first occurrence of freezing temperatures in the fall and their associated probabilities.

STATION	Date of First Fall Frost Probability 25%	50%	75%	90%
Amenia	Sept. 7	Sept. 18	Sept. 26	Oct. 3
Bottineau	Sept. 7	Sept. 15	Sept. 23	Sept. 30
Bowman	Sept. 7	Sept. 15	Sept. 22	Oct. 1
Carson	Sept. 7	Sept. 15	Sept. 23	Sept. 30
Cooperstown	Sept. 9	Sept. 17	Sept. 25	Oct. 2
Crosby	Sept. 6	Sept. 14	Sept. 22	Sept. 29
Dickinson	Sept. 7	Sept. 15	Sept. 23	Oct. 1
Edgeley	Sept. 8	Sept. 16	Sept. 25	Oct. 1
Fessenden	Sept. 5	Sept. 12	Sept. 21	Sept. 26
Garrison	Sept. 8	Sept. 16	Sept. 24	Oct. 1
Grafton	Sept. 7	Sept. 15	Sept. 23	Sept. 30
Grand Forks	Sept. 11	Sept. 18	Sept. 26	Oct. 2
Granville	Sept. 6	Sept. 14	Sept. 22	Sept. 29
Hansboro	Sept. 5	Sept. 14	Sept. 22	Sept. 30
Hettinger	Sept. 8	Sept. 16	Sept. 24	Oct. 2
Jamestown	Sept. 8	Sept. 16	Sept. 24	Oct. 1
Langdon	Sept. 6	Sept. 14	Sept. 22	Sept. 29
Lisbon	Sept. 9	Sept. 17	Sept. 25	Oct. 3
Maddock	Sept. 6	Sept. 14	Sept. 21	Sept. 29
Mandan	Sept. 11	Sept. 19	Sept. 27	Oct. 5
Marmarth	Sept. 7	Sept. 15	Sept. 23	Oct. 1
Mayville	Sept. 9	Sept. 16	Sept. 26	Sept. 30
McClusky	Sept. 7	Sept. 15	Sept. 23	Sept. 30
McLeod	Sept. 9	Sept. 17	Sept. 25	Oct. 2
Minot	Sept. 7	Sept. 15	Sept. 23	Sept. 30
Mohall	Sept. 7	Sept. 15	Sept. 23	Oct. 1
Napoleon	Sept. 7	Sept. 15	Sept. 23	Oct. 1
Oakes	Sept. 9	Sept. 17	Sept. 25	Oct. 2
Parshall	Sept. 6	Sept. 14	Sept. 22	Sept. 29
Pembina	Sept. 7	Sept. 15	Sept. 23	Sept. 30
Pettibone	Sept. 5	Sept. 13	Sept. 21	Sept. 28
Powers Lake	Sept. 6	Sept. 14	Sept. 22	Sept. 30
Towner	Sept. 6	Sept. 13	Sept. 21	Sept. 28
Wahpeton	Sept. 11	Sept. 19	Sept. 27	Oct. 4
Watford City	Sept. 7	Sept. 15	Sept. 23	Sept. 30

rieties of barley, rye and wheat all exhibit decreased yield when sown late as a result of high temperatures and high evaporative losses during the reproductive stage. In addition, farmers who have to seed late in the spring must face the risk due to the shortened length of favorable temperature conditions before the first killing frost in the fall. Pengra and Magnuson (15) indicated that a temperature of 32° F will damage oats, wheat and barley at their flowering stage, while temperatures of 28° F will result in some damage to small grain during the fall near harvest time.

As a guide in decision-making when "late" planting is considered, the date of occurrence of the first fall freeze is given at various levels of probability in Table 1. The table may be used in determining the latest date in the planting season that a certain crop should be planted to avoid freeze damage in the fall. For example, 75 per cent of the time, a freeze comes as early as September 25 at Oakes. If a farmer in that area wishes to plant a 120-day corn hybrid, he could count back 120 days before September 25 to determine the latest date he should probably seed. Following this procedure, he should plant no later than May 28 if he wishes to avoid possible freeze damage to his crops in the fall. If he chooses to risk his crops at 50-50 odds, he may seed as late as May 18 (120 days before September 17, Table 1).

It is common knowledge that crops planted later during the warmer temperatures in late spring or early summer develop faster than those seeded earlier during lower temperatures. The calendar-day ratings (sowing to harvesting) of both corn and small-grain varieties in this situation becomes less useful as a guide. For this and other reasons, a heat-unit system for rating crop maturity has been introduced. This is discussed further in the later sections of this publication.

Critical Temperatures During the Growing Season

Low Temperatures

Below and near-freezing air temperatures offer a special hazard to agriculture in North Dakota during the immediate weeks after planting and during early fall before harvest. Decker (2) characterized degrees of severity of freezes, depending on the extent of the temperature fall. He recognized three types of freeze occurrences:

1. Light freeze — when air temperatures dip into the range from 28° to 32° F.
2. Moderate freeze — when nighttime temperatures fall in the range between 24° to 28° F.
3. Severe freeze — when temperatures dip below 24° F.

Parker (14) suggested that typical cool-season crops such as those raised in North Dakota including oats, rye, wheat and barley have cardinal temperatures (below which normal growth and development is impeded) ranging from 32° to 41° F. It has already been pointed out that these same crops may suffer low temperature injuries in their flowering stage when temperatures dip below 32° F (15).

Probabilities of at least one occurrence of subfreezing morning temperature during each week from May through September are shown in Figure 10 for 35 locations in the state. These figures provide a picture of freezing and chilling injury risks across North Dakota throughout the growing season. Subfreezing temperatures have very seldom (less than one out of every 20 years) been observed during the period from mid-June through mid-August.

While small grains may survive single, isolated occurrences of these low temperatures, exposure for an extended period of time may be detrimental. Protection from injuries due to low temperatures might be attempted by horticulturists and gardeners for a single night or two. However, usually it is impractical to maintain protection for extended periods. Extended periods of freezing temperatures also affect the type and amount of outdoor work a farmer or construction crew can do.

Probabilities of five days or more in a row with minimum temperatures below 32°F occurring in spring and autumn are presented in Figure 10. The maps presented cover the periods March 22 through May 9 in the spring and October 4 through November 21 in the fall.

There is better than 50 per cent chance for early morning freeze to last more than five days in a row across the state until mid-April in the spring and as early as mid-October in the fall. Higher probabilities exist for extended freeze in the spring in the north and north central portions of the state. In the fall, the trend is for greater chances of five-day morning freezes as one goes northwesterly across the state.

Extended periods of early morning freezes are very likely to occur in March and April across North Dakota with better than 60 per cent probability existing until the middle of April. In the fall, not until the last of October is there greater than 50 per cent chance that at least a five-day duration of early morning freezes will occur in most of the state.

High Temperatures

Injury to field crops can result from extremely high temperatures. Parker (14) gave 98.6° F as an upper cardinal temperature for oats, wheat and barley; and 111° - 112° F for hot season crops such as melons and sorghums. Jensen and Lund (6) reported that frequent occurrence of temperatures above 90° F reduce final wheat yields in North Dakota even under favorable soil moisture conditions. The chances of having at least one occurrence of temperatures above 90° F during selected weeks from May through mid-September is shown in Figure 12.

The maps show two-week intervals since the probabilities for weeks between those presented can easily be estimated by visual interpolation. There is more than 50 per cent chance that at least one day of each week in mid-July through mid-August will have a temperature of 90° F or above. In May, when most cereal crops are well into their seedling stage, there is about 10 to 30 per cent chance of a 90-degree temperature across the state.

When extremely high temperatures occur during prolonged rainless periods, the result can be totally catastrophic to crop yields. It is generally agreed that temperatures over 100° F are detrimental to crop production (2). In North Dakota, however, there has never been an occurrence of five or more days in a row when maximum temperatures exceeded 100° F.

The effects of extended periods of high temperatures are aggravated when associated with prolonged lack of precipitation. The likelihood that 90-degree temperatures and above will occur for at least five days in a row are given in Figure 13 for four weeks in the summer in which they occur in at least one out of 10 years. Such high temperatures may be expected to occur during the period from the middle of July through the first week in August with no higher than 20 per cent probability in most of the state. Higher probabilities (20-25 per cent) exist in the southwestern portions of the state during the last two weeks in July.

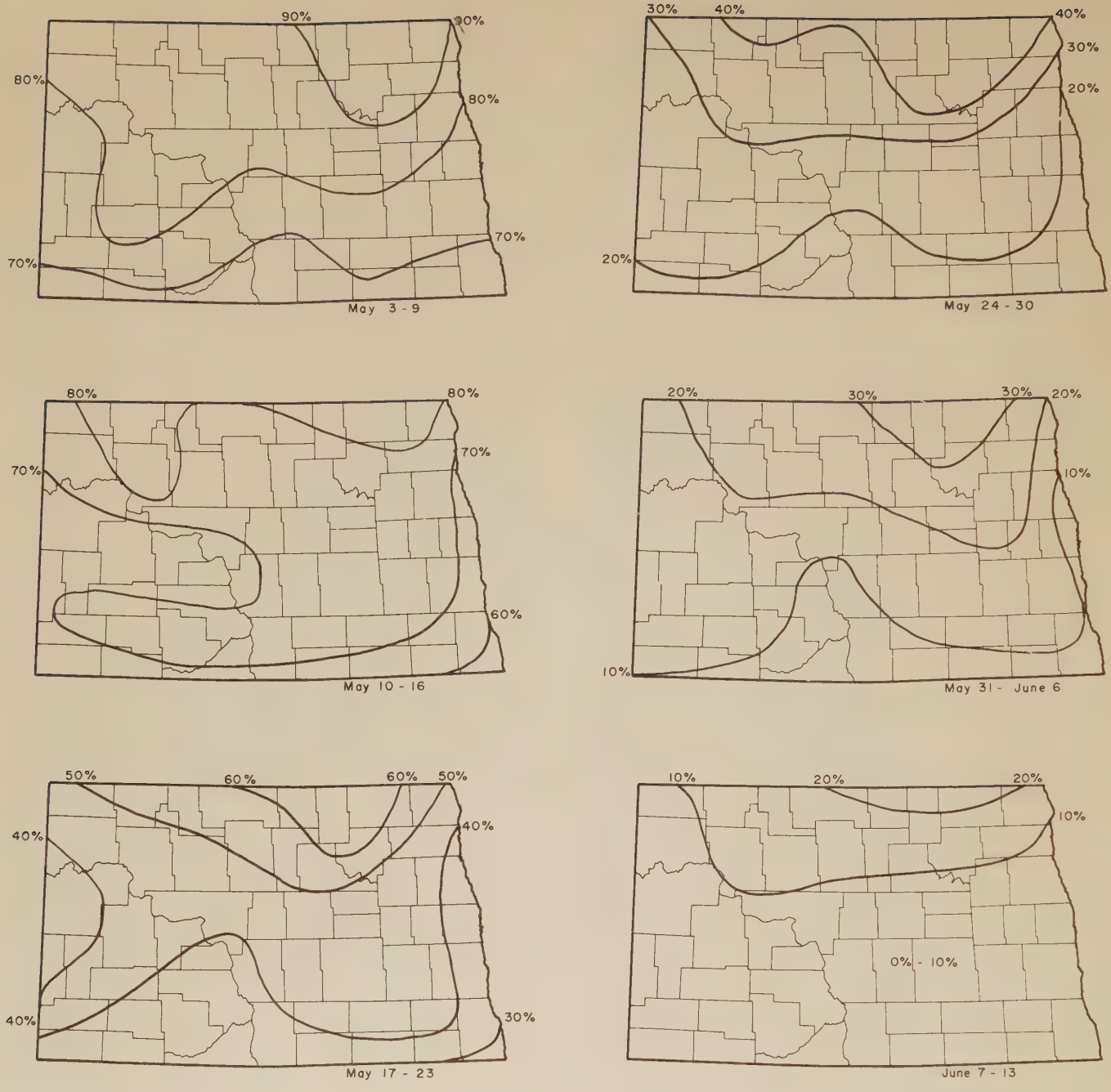
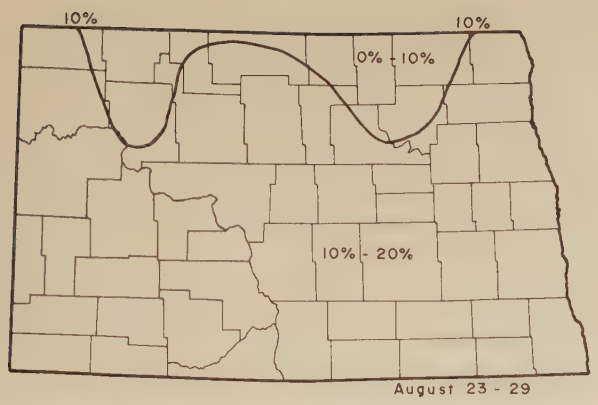
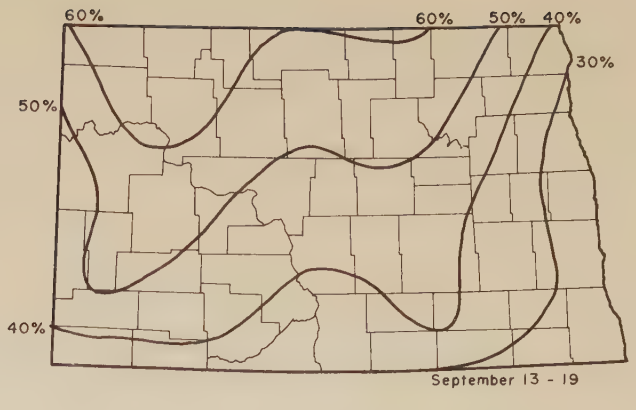
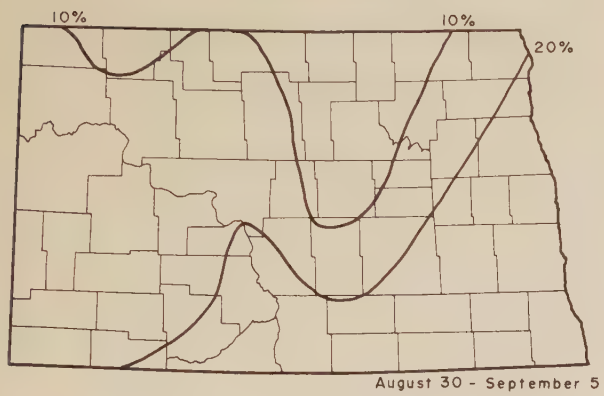
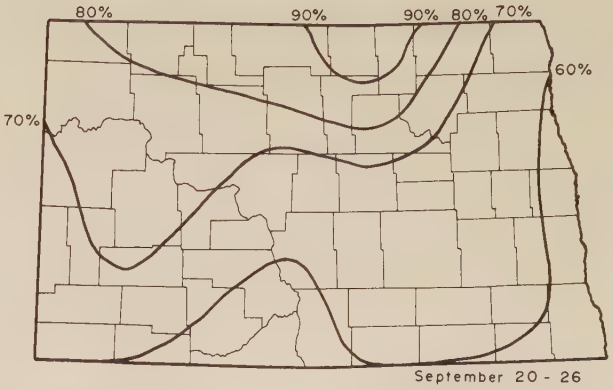


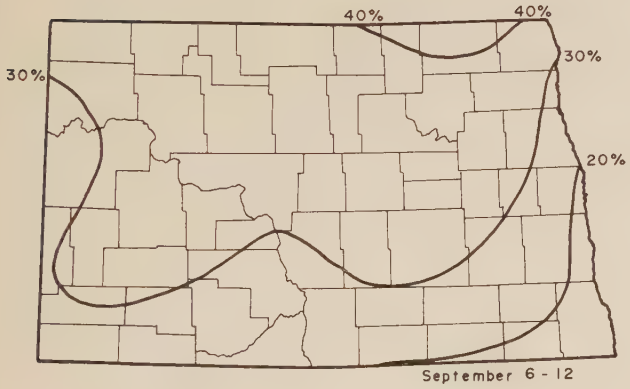
Figure 10. The probabilities of at least one occurrence of 32° F and lower temperatures in selected weeks during the "growing season."

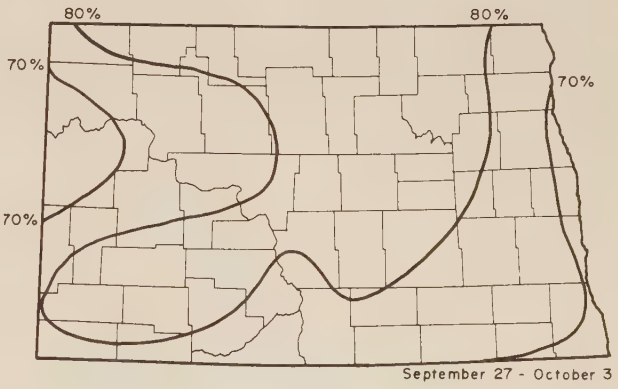












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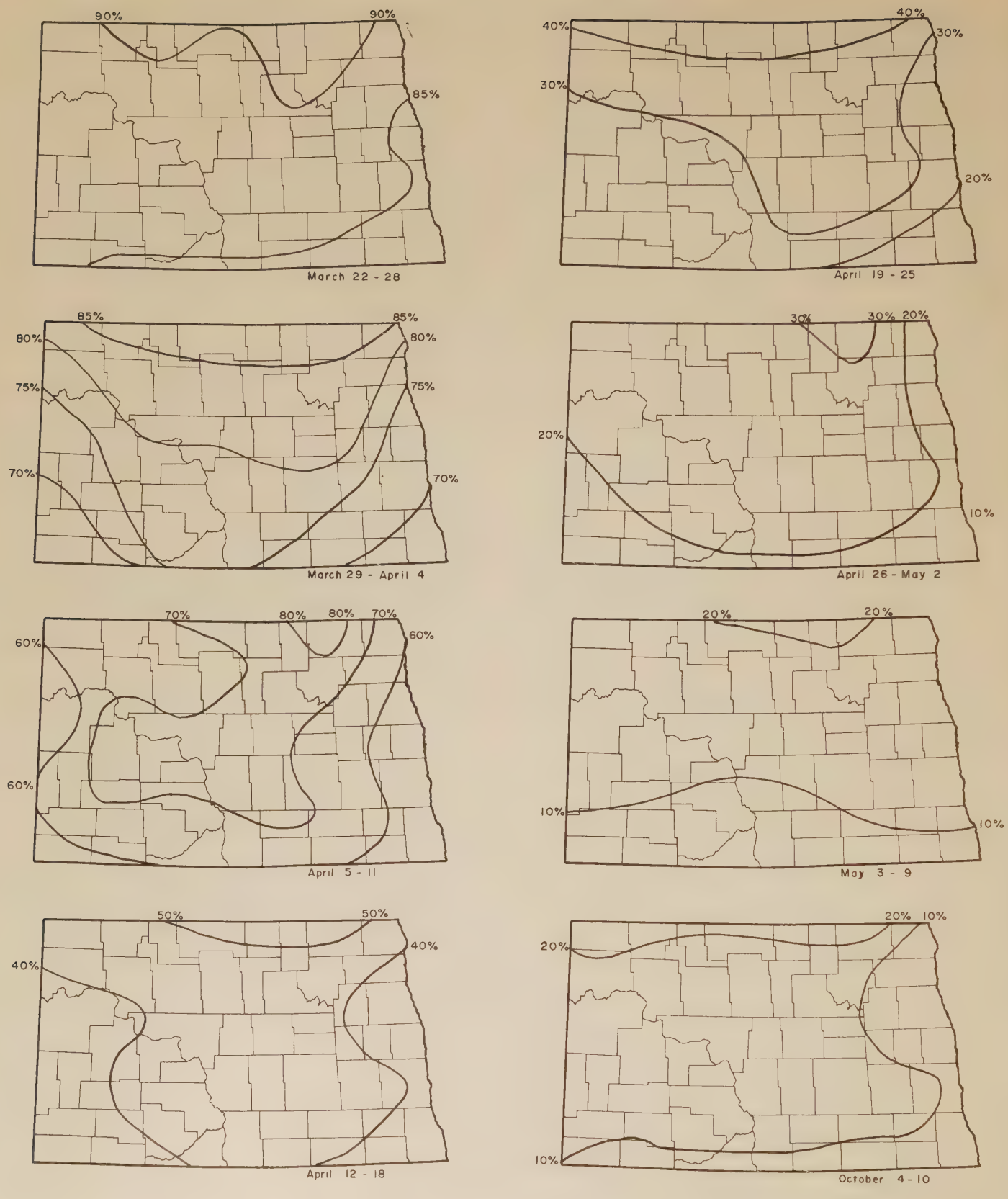
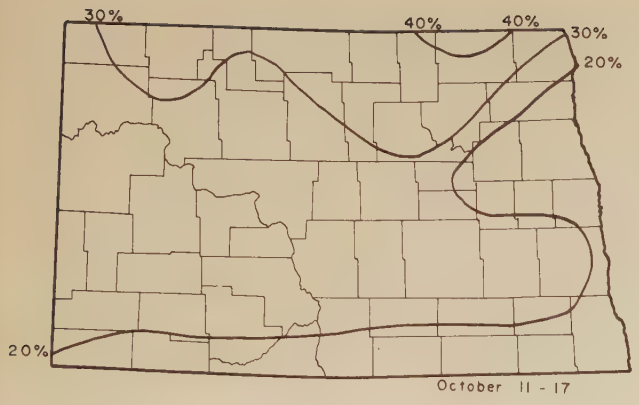
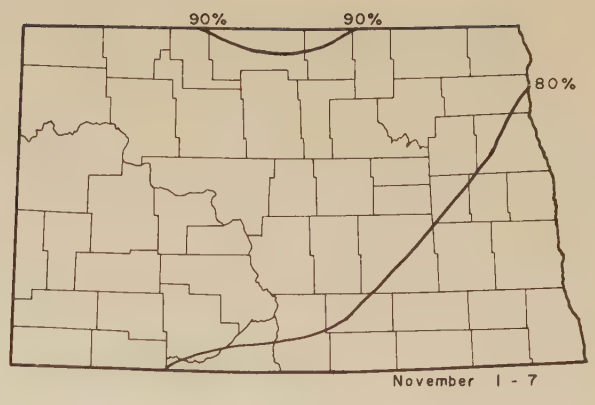
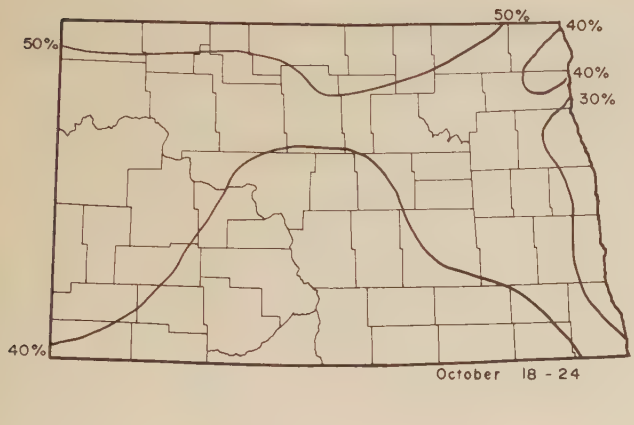
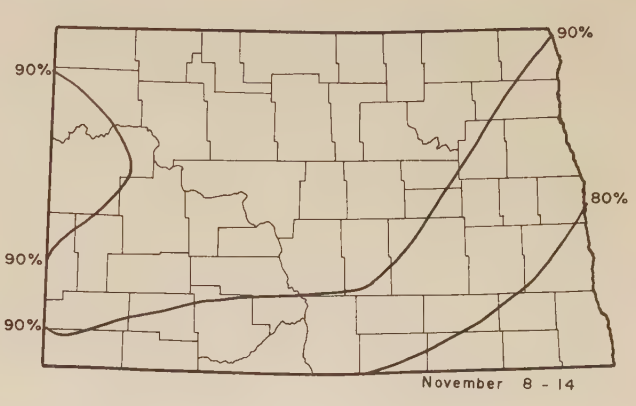


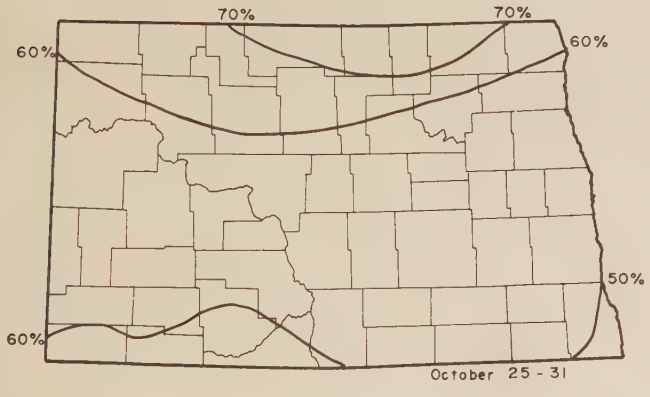
Figure 11. The probabilities that the minimum temperatures will be 32° F and below for five days in a row in selected weeks of the spring and fall.

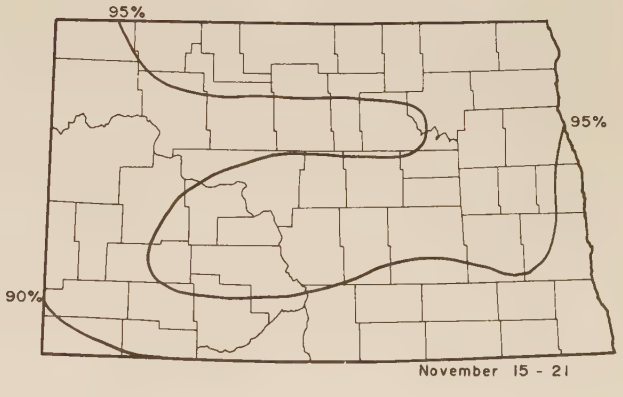












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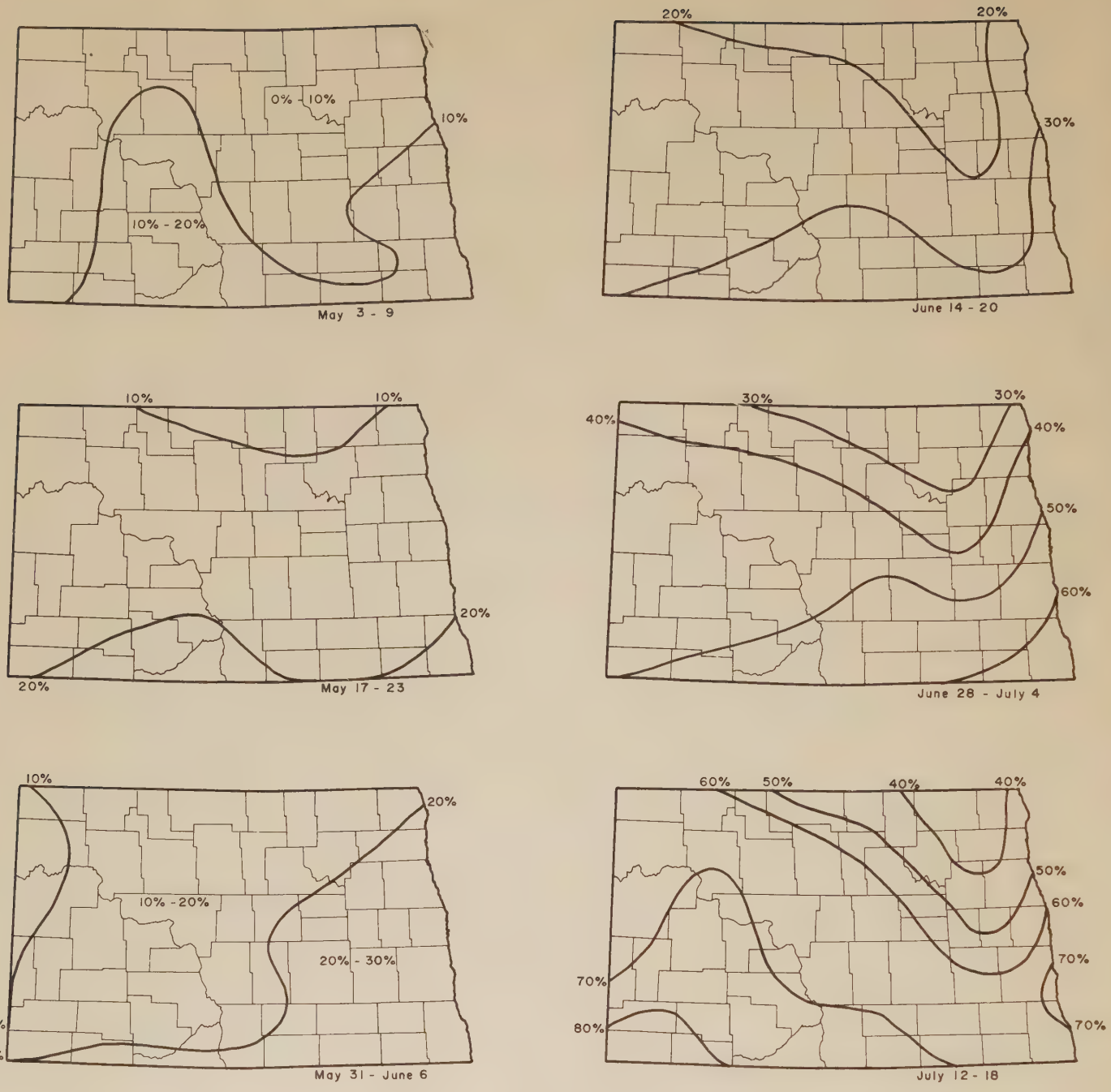
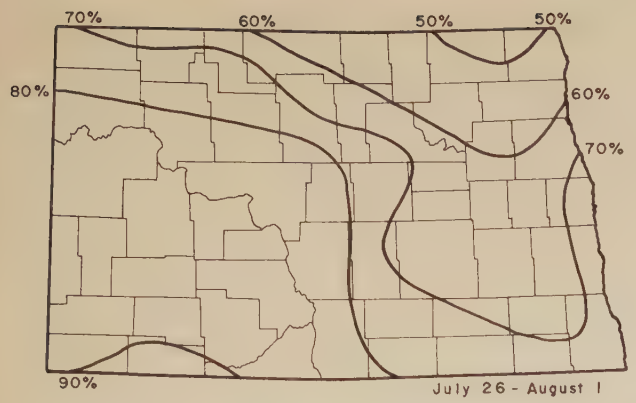
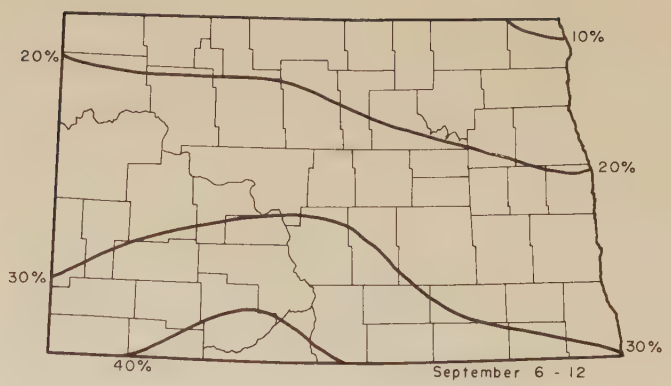
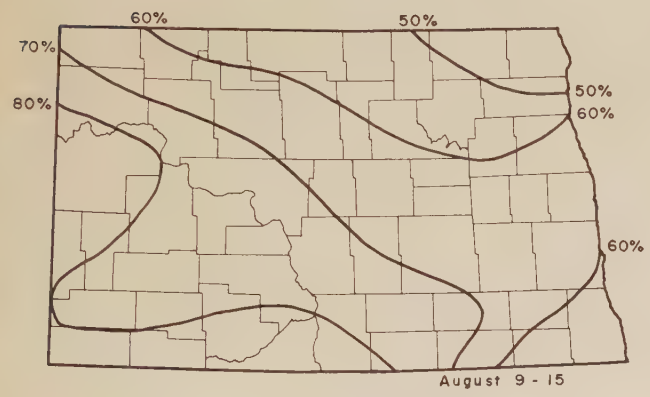
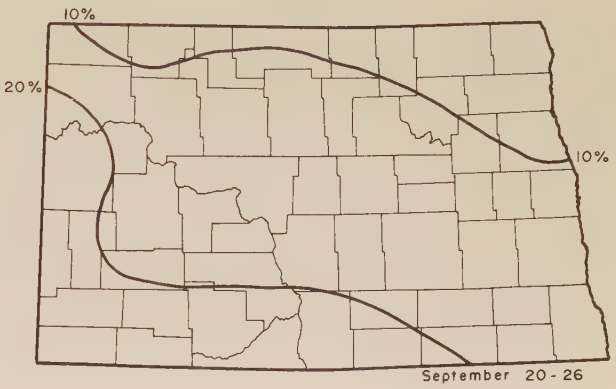


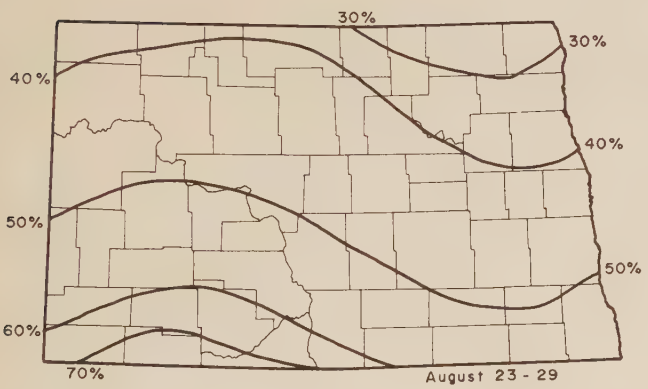
Figure 12. The probabilities of at least one occurrence of 90° or higher temperatures in selected weeks of the growing season.











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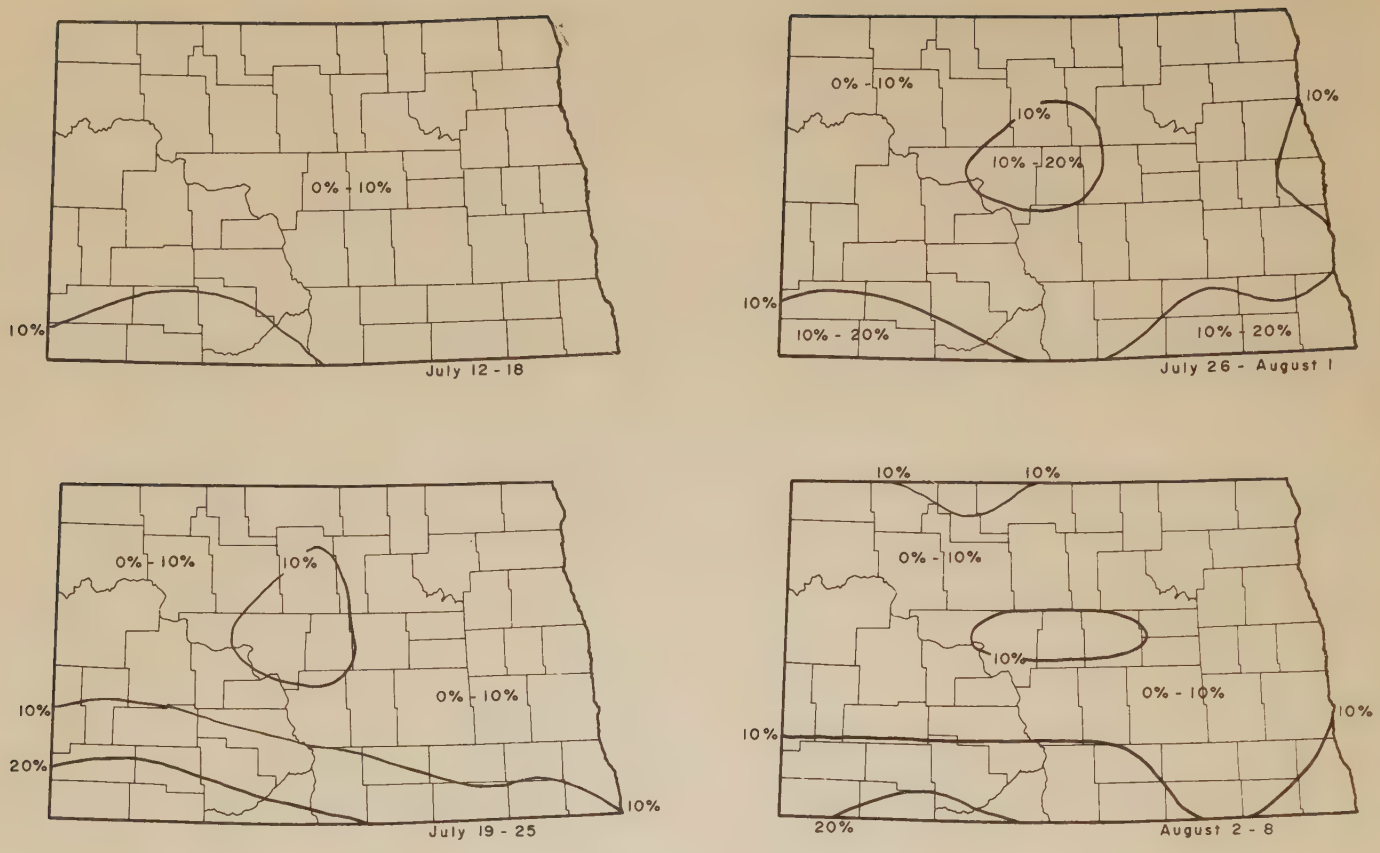


Figure 13. The probabilities that the maximum temperatures will be 90° F and higher for five days or more in a row.

WINTER TEMPERATURES

North Dakota has always been known for its long and cold winters. Below freezing temperatures are registered on 180-210 days of the year in North Dakota, while subzero temperatures occur on 35-65 days each year (7). During the winter the southwest corner of the state is usually 11° to 15° F warmer than the northeast.

Sub-zero Temperatures

Sub-zero temperatures always are a convenient indicator of extreme cold. When these temperatures occur with high winds, livestock must receive special protection, and man's outdoor activity is greatly curtailed or made much more difficult.

The chances for five days or more in a row when sub-zero minimum temperatures occur in selected weeks during the winter are presented in Figure 14.

The maps shown are only those for weeks when probabilities of sub-zero minimum temperatures for more than five days in a row occur at least 10 per cent of the time. Only the probabilities for every two-week interval are presented. Such occurrence starts at about the first of December and has up to 60 per cent expectation in the northeast portions of the state in the last week of January, tapering off until the second week of March when there is only a 10 per cent chance of such occurrence.

Above-freezing Temperatures

Extended occurrence of above freezing temperatures during the winter has a bearing on planning and completing outdoor work by construction workers and other engineering activities. Such information also lends significance to how fast the snow cover melts in late winter as related to forecasting floods in the flood plain areas of the state. Extended occurrence of above-freezing temperatures also has some bearing on the extent of soil thawing, since soil temperatures with and without snow cover are highly correlated to air temperatures. Frequency of freeze-thaw cycles in the winter also influences soil structure, soil heaving and thus affects seedbed preparation in the spring.

Figure 15 shows the probabilities of the occurrence of 32° F and above for five days or more in a row in the weeks of the late fall, winter and early spring across the state, for each two-week interval.

During the winter across the state, above freezing maximum temperatures for at least five days in a row occur less than half of the time from the second week in December through early March. Until early December in early winter and from mid-March in the spring, there is better than 50 per cent chance that above freezing maximums will occur for more than five days in a row.

C. GROWING DEGREE DAYS

Effective heat units, or sometimes simply called "heat units," are arithmetic accumulations of daily mean temperatures above or below a certain threshold value. They are used as a general means of relating environmental air temperature to plant growth, development and maturation, cooling requirements in the summer, and heating requirements in the winter. For such practical applications usually they are referred to as growing degree days (GDD), heating degree days and cooling degree days, respectively.

Different species of plants have different base or threshold temperatures below which they cannot normally grow, develop and produce. At temperatures higher than this base value, the rate of plant growth and development is approximately proportional to the amount of heat available as indicated by air temperatures. This relationship usually holds true until an upper limiting temperature above which plants may be injured or killed.

Parker (14) suggested the limits of temperature requirements for most crops as follows:

Cool-season crops, including oats, rye, wheat and barley;

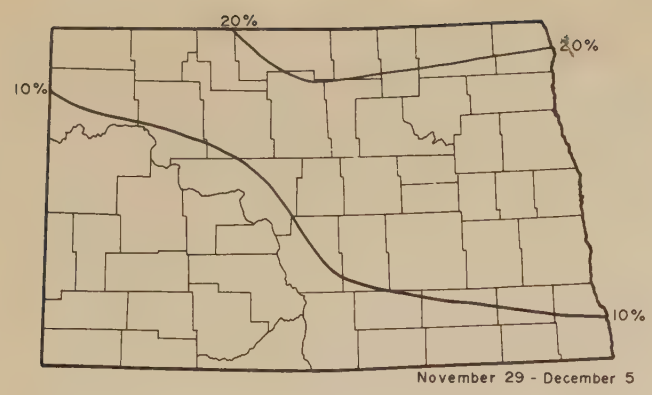
Lower limit: 32° to 41° F
Upper limit: 88° to 98.6° F

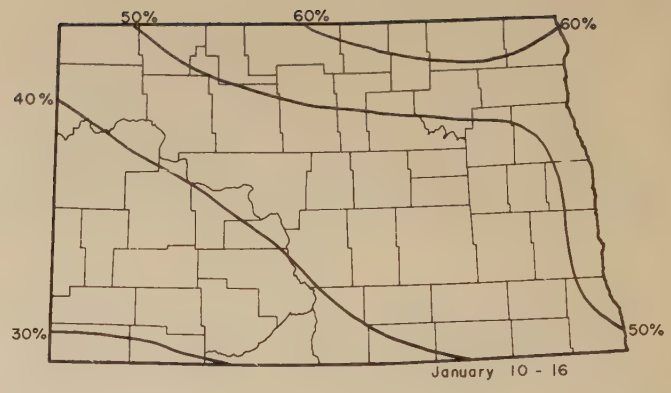
Hot-season crops, including melons and sorghums;

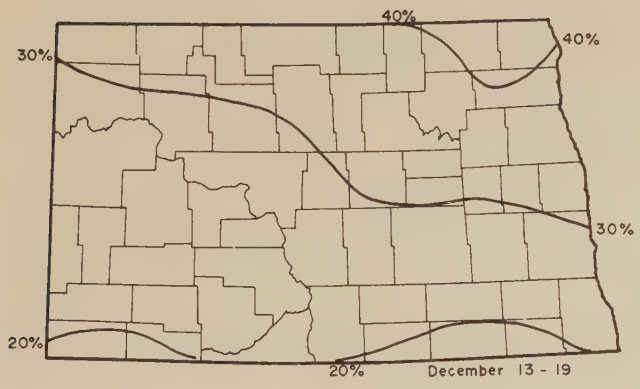
Lower limit: 59° to 64.4° F
Upper limit: 111° to 122° F

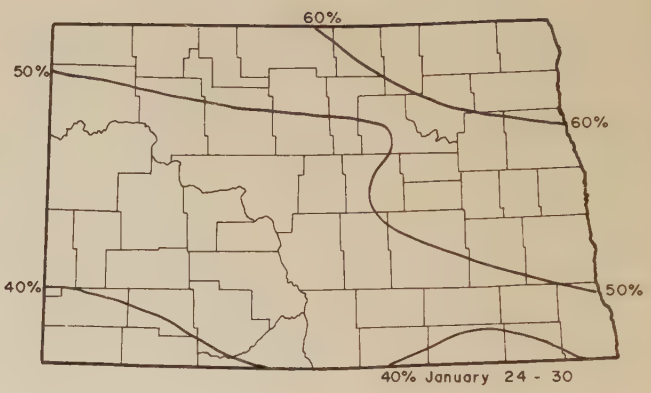
Dethier and Vittum (3) outlined the base temperatures for several economically important plants for the purpose of determining growing-degree day conditions in the northeast region of the United States:

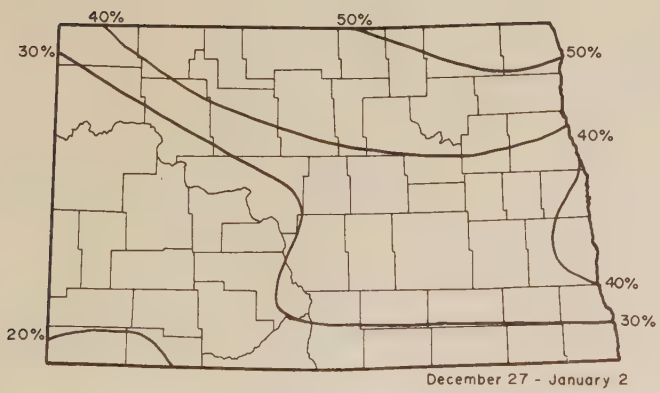
Spring wheat	37°-40° F
Canning peas	40° F
Oats	43° F
Potatoes	45° F
Sweet corn, snap beans	50° F
Lima beans, tomatoes	50° F
Field corn	50° F

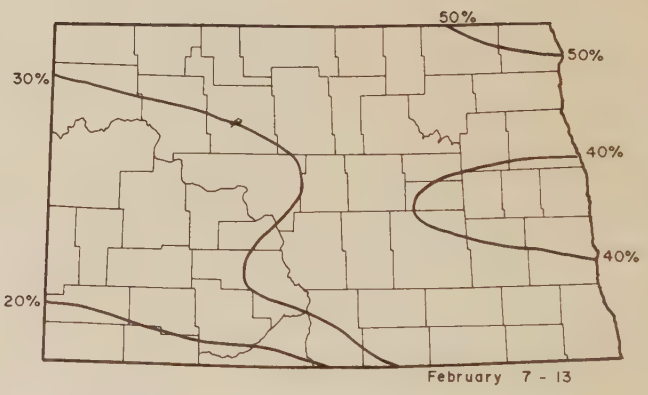












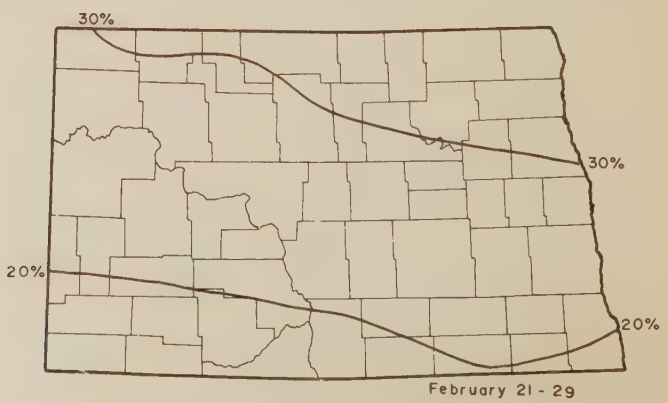


Figure 14. The probabilities that the minimum temperatures will be 0° F and below for five days in a row in the winter.

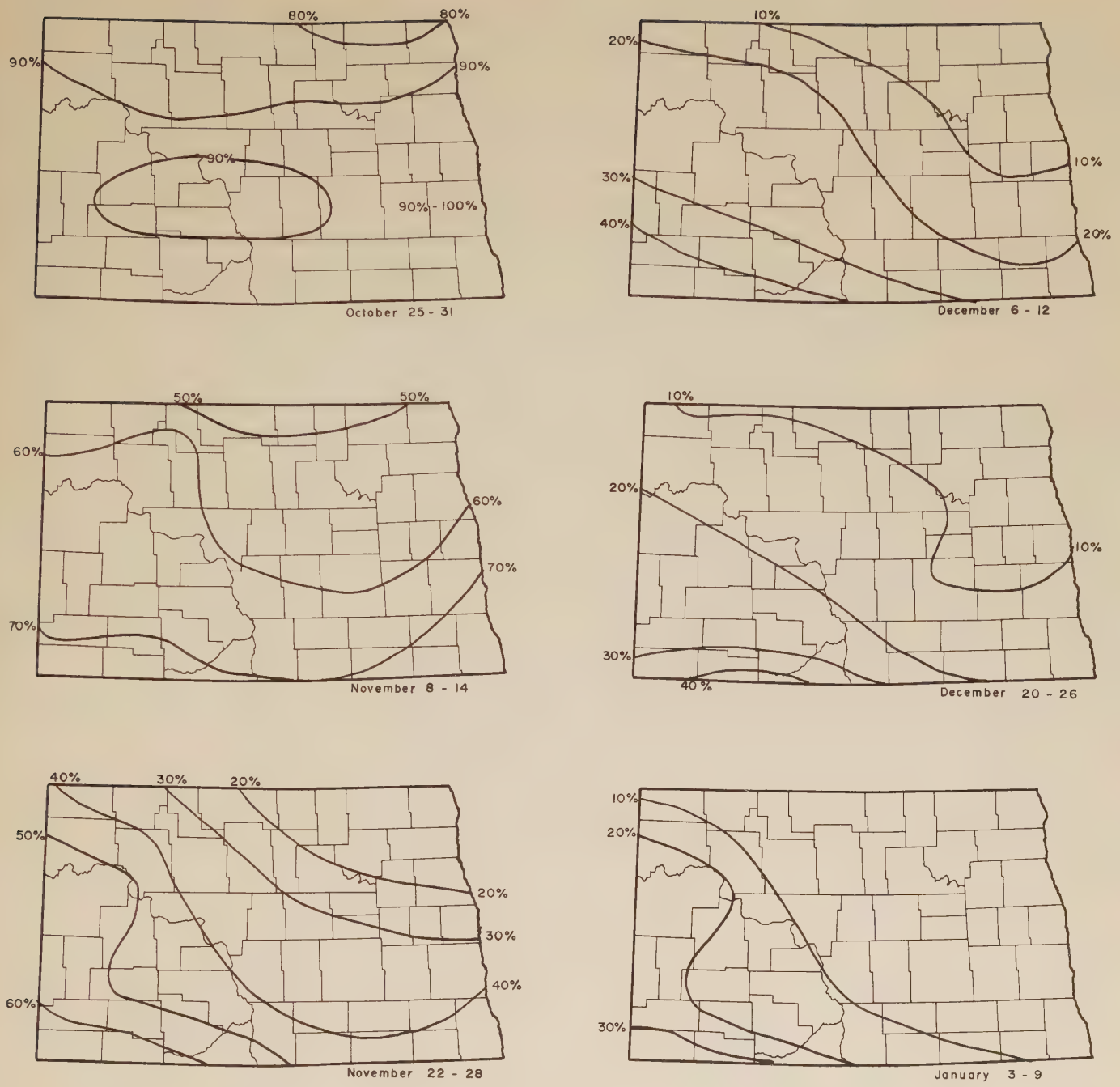
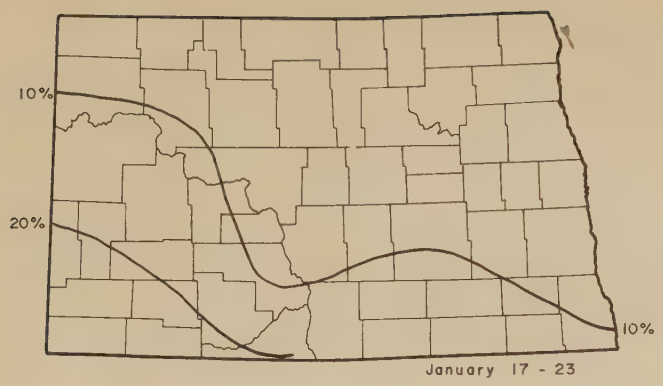
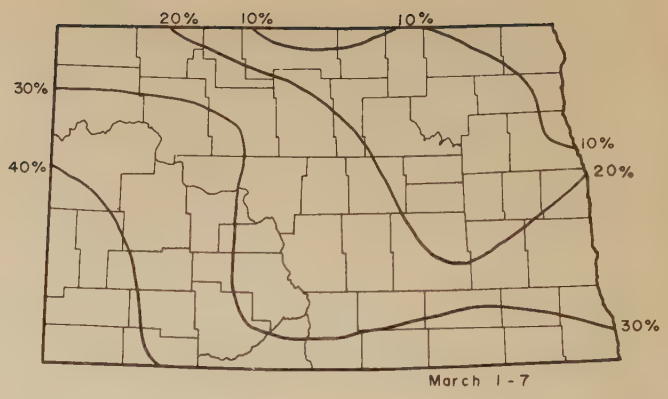
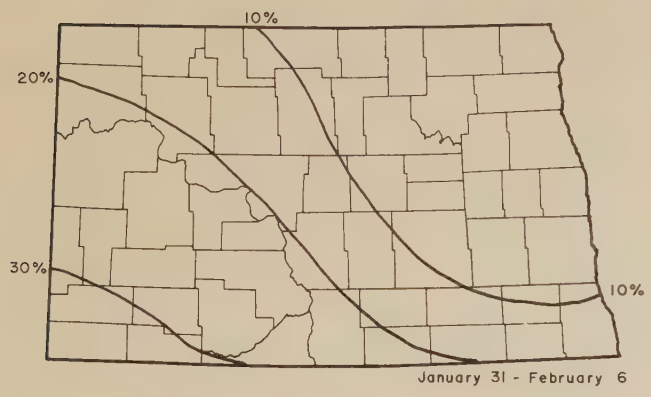
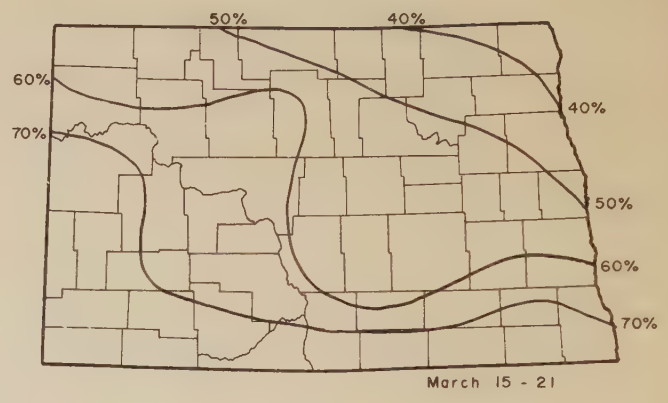


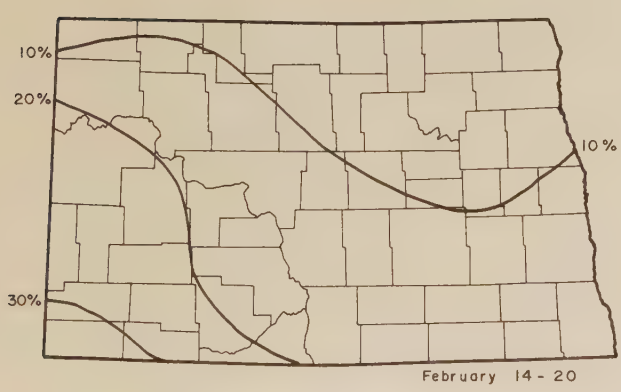
Figure 15. The probabilities that the maximum temperatures will be 32° F and above for five days in a row in the winter.











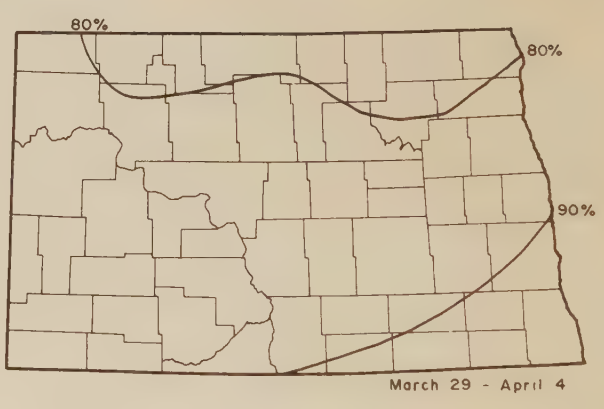


Figure 15. (Continued)

GDD and Corn Maturity

Corn maturity ratings usually have been based on the number of calendar days between planting and silking. Many corn breeders realize that this method has serious limitations, particularly when a hybrid is grown throughout a widely divergent geographical area and since it is common knowledge that it takes fewer days for a corn plant to reach silking if it is planted later in the season or farther south. Newman (9) stated that any system more accurate than the "calendar-day" system must be based on the environmental factor largely responsible for this variation in corn maturity.

As early as 1914, Lebenhauer (8) determined that corn growth begins about 41° F air temperature, but is extremely slow below 50° F. Although corn can survive temperatures between 32° and 110° F, optimum growth and development occurs around 86° F. Realizing that corn plants may not grow when temperatures get too high, GDD calculations suggested by a number of researchers consider only the accumulation of temperature deviations from a lower limit of 50° F to an upper limit of 86° F.

The mathematical expression for calculating growing-degree day (GDD) is:

$$\text{GDD} = \frac{\text{Max. Temp.} + \text{Min. Temp.}}{2} - \text{Base Temp.}$$

The formula is then adjusted to correct for extreme high or low temperatures. Minimum temperatures below 50° F are counted as 50° and temperatures above 86° are counted as 86°.

For example, if the maximum temperature for the day is 82° and the minimum is 60°:

$$\text{GDD} = \frac{82° + 60°}{2} - 50°$$
$$= 71 - 50$$
$$= 21$$

Or, on another day, the high temperature is 88° and the low is 46° F:

$$\text{GDD} = \frac{86° \text{ (for 88°)} + 50° \text{ (for 46°)}}{2} - 50°$$
$$= 68 - 50$$
$$= 18$$

A general picture of the number of growing degree days across North Dakota from the average date of last spring freeze to the average date of first fall frost, or during the freeze-free periods at different locations, is shown in Figure 16.

Corn planting dates in areas growing dent or silage corn in the state vary from around the middle of May through June. In selecting hybrids with maturity ratings based on GDD, use Table 2 as a guide. For example, let us say that a farmer in Richland county wishes to plant in the last week of May and hopes to have mature corn before the first killing frost in the fall. It will be wise for him to choose a hybrid with a GDD rating of 2200 or less.

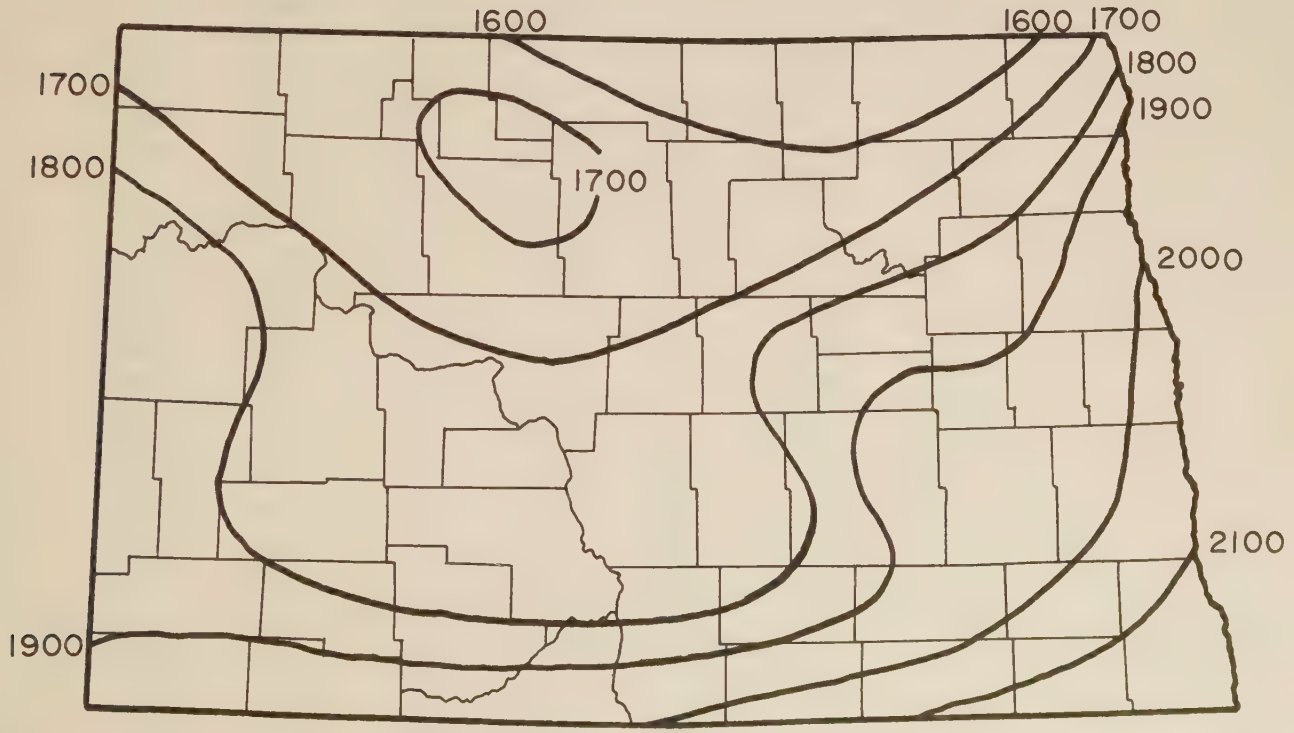


Figure 16. The average number of accumulated GDD's during the freeze-free period in North Dakota (Base of 50° F).

Or, a corn farmer in LaMoure, for example, could plant as early as May 10. He could choose a corn hybrid with a GDD rating of 2,061 or less and minimize the risk offered by killing frost that is expected to occur in September.

Applications to Small Grains

Nuttonson (11, 12, 13) stated that rye, wheat and barley growth ceases when temperatures fall below 40° F since the plant becomes practically dormant. He calculated the accumulated heat units using 40° F base from sowing until various stages of growth of wheat, barley and rye. He made use of extensive data from the Northern Great Plains and several agriculturally and climatically similar areas in the Soviet Union, Finland, Poland and Czechoslovakia. Summarized below are some of the results of his analysis.

Table 2. The average number of GDD's from selected dates in the planting season to the date of first killing frost (28° F or lower); base of 50° F.

	Number of GDD (Base of 50° F) From Date To First Killing Frost (28° or Lower)						
STATION	May 3	May 10	May 17	May 24	May 31	June 7	June 14
Amenia	2182	2142	2090	2019	1936	1848	1757
Bottineau	1841	1813	1774	1722	1654	1579	1498
Bowman	2079	2039	1993	1935	1867	1795	1716
Carson	2077	2038	1987	1927	1852	1774	1686
Cooperstown	2093	2057	2010	1949	1875	1790	1698
Crosby	1863	1835	1793	1740	1668	1600	1518
Dickinson	1920	1888	1844	1788	1723	1651	1570
Edgeley	2101	2061	2011	1949	1874	1792	1707
Fessenden	2094	2059	2011	1946	1872	1784	1693
Garrison	2002	1965	1922	1862	1791	1715	1630
Grafton	2078	2036	1989	1920	1842	1755	1661
Grand Forks	2155	2117	2062	1992	1917	1829	1736
Granville	1978	1944	1899	1840	1765	1686	1601
Hansboro	1687	1657	1623	1573	1509	1439	1364
Hettinger	2137	2096	2045	1980	1906	1832	1743
Jamestown	2126	2090	2041	1974	1896	1811	1719
Langdon	1782	1752	1712	1656	1594	1524	1445
Lisbon	2171	2130	2078	2011	1931	1841	1746
Maddock	1972	1935	1887	1821	1748	1669	1583
Mandan	2168	2130	2079	2015	1941	1861	1768
Marmarth	2087	2049	2001	1941	1869	1797	1713
Mayville	2230	2188	2134	2064	1979	1887	1792
McClusky	2022	1988	1941	1881	1808	1731	1650
McLeod	2287	2243	2184	2114	2029	1934	1835
Minot	1926	1895	1848	1795	1727	1655	1569
Mohall	1983	1950	1900	1837	1764	1684	1599
Napoleon	2022	1985	1938	1876	1805	1726	1639
Oakes	2256	2215	2162	2092	2014	1922	1823
Parshall	1914	1876	1830	1769	1699	1622	1537
Pembina	1959	1920	1876	1815	1740	1654	1565
Pettibone	1945	1904	1860	1805	1733	1659	1571
Powers Lake	1845	1817	1783	1734	1668	1603	1528
Towner	1989	1948	1899	1836	1756	1672	1584
Wahpeton	2385	2336	2276	2200	2110	2012	1909
Watford City	2158	2121	2062	1993	1917	1838	1750

Table 3. Estimated GDD requirements for small grains (after Nuttonson, (11, 12, 13).

	Accumulated GDD (40° F Base)		
	Sown to Headed	Headed to Ripe	Sown to Ripe
SPRING VARIETIES			
Spring Wheat (Thatcher)	1,053	974	2,027
Spring Barley (Trebi)	1,101	864	1,965
	Mar. 1 to Headed	Headed to Ripe	Mar. 1 to Ripe
WINTER VARIETIES			
Winter Wheat (Kharkof)	978	998	1,976
Winter Rye (Dakold)	630	1,368	1,998

Although no evaluations for currently grown small grain varieties are yet available it is quite evident from Table 3 that 2000 growing degrees from sowing to ripening for spring varieties and from March 1 to ripening for winter varieties is a reasonable threshold estimate of growing degree day requirement for small grains. Assuming selected weeks of sowing, the accumulated GDD's from a base of 40° F were calculated to show the variations of expected ripening dates across the state according to its temperature distribution. These are presented in Figure 17.

To illustrate the use of these maps, if a farmer at Bottineau plants on April 19, for example, he can expect on the average (50 per cent probability) that his grain is ripe about August 4. This corresponds to about 107 calendar days between sowing and ripening. It is interesting to note that if he planted two weeks later, May 3 for example, 2000 heat units will have been accumulated at about August 6, or only two days later than if he planted on April 19. Furthermore, if he planted on May 31, he expects ripening about August 19, which corresponds to only 80 days between sowing and ripening.

To stress this point, you may notice that regardless of the planting date in March, you can expect the same ripening date for small grains. This is due to the fact that growing degrees usually available in March are negligible as they accumulate faster as the warmer summer temperatures occur.

The maps in Figure 17 may be used as a guide to schedule agronomic field operations, along with other factors such as soil moisture conditions in the early seedling growth stages, high temperatures during the blossoming stage, and freezing temperatures in the spring and fall.

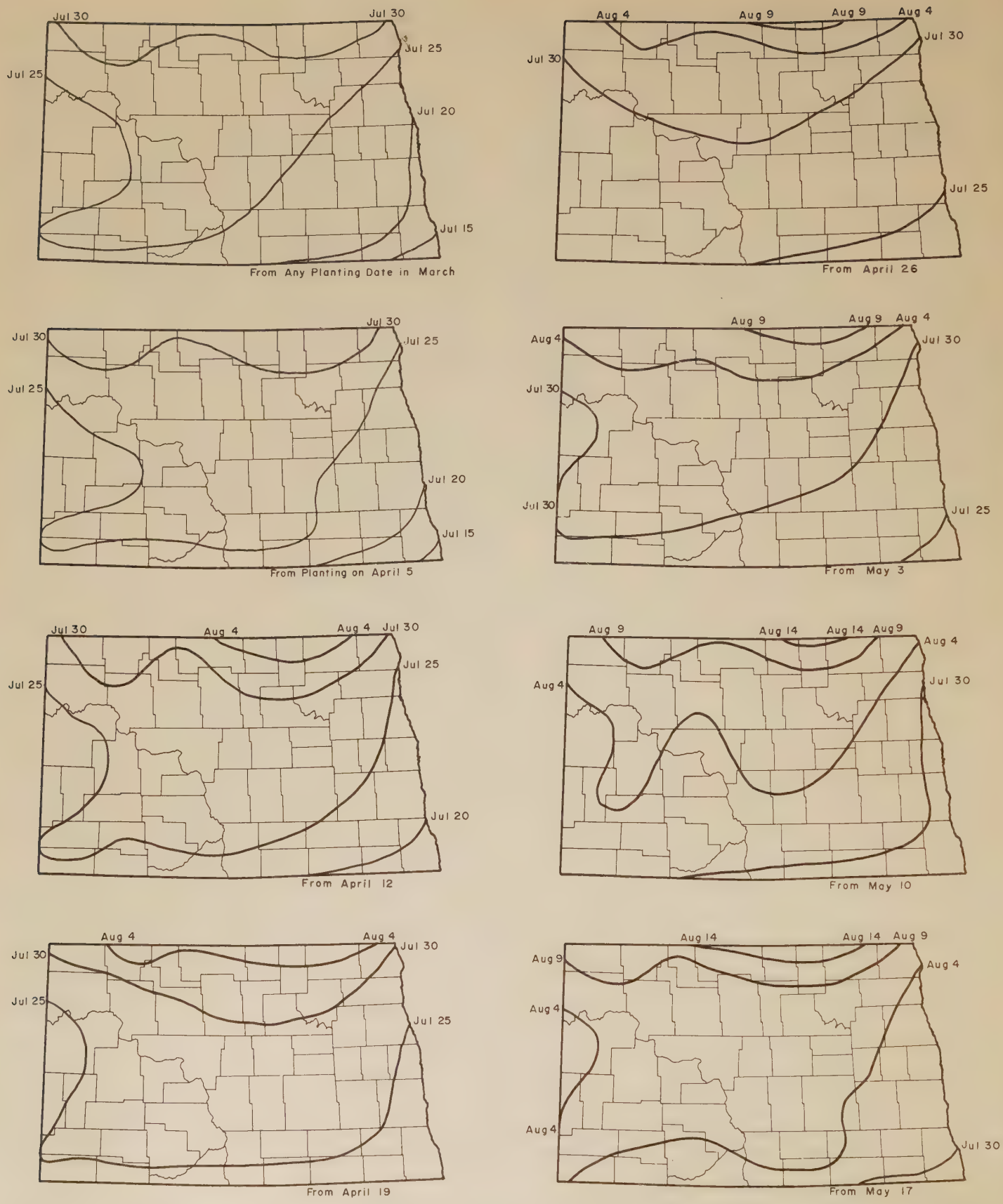
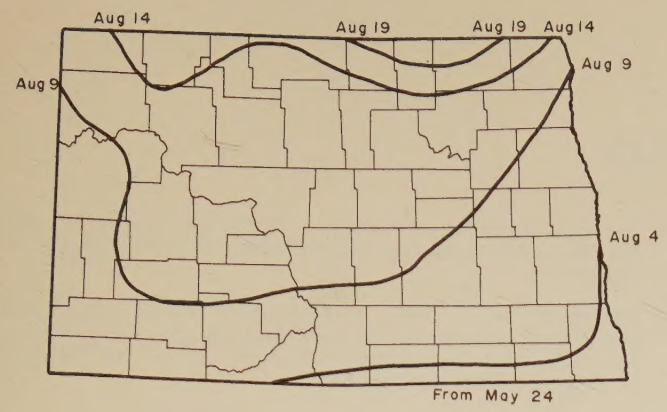
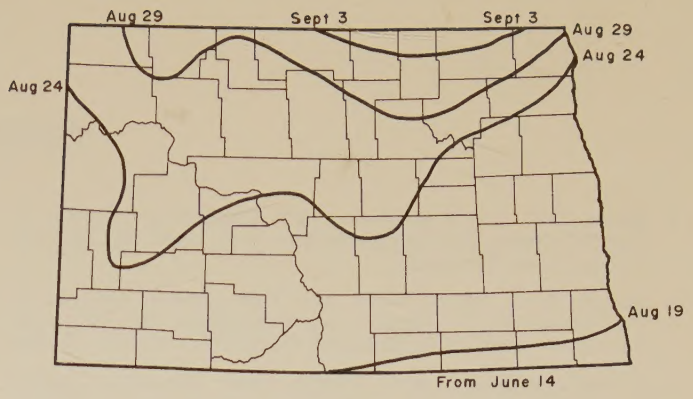
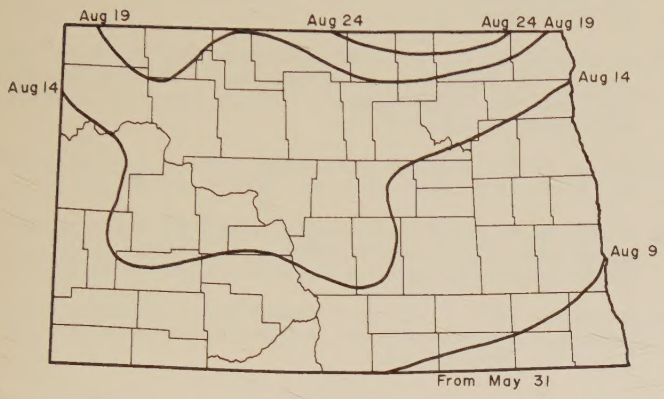
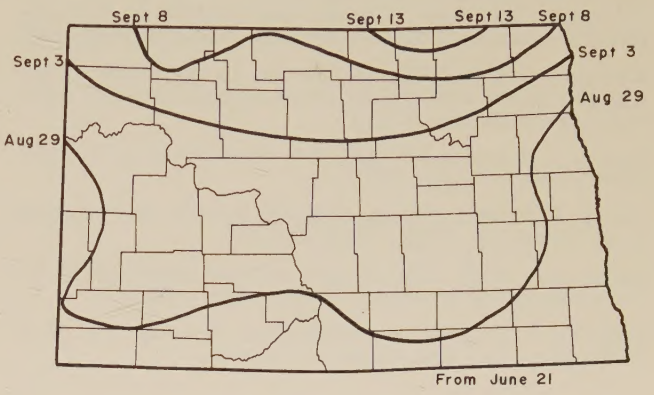


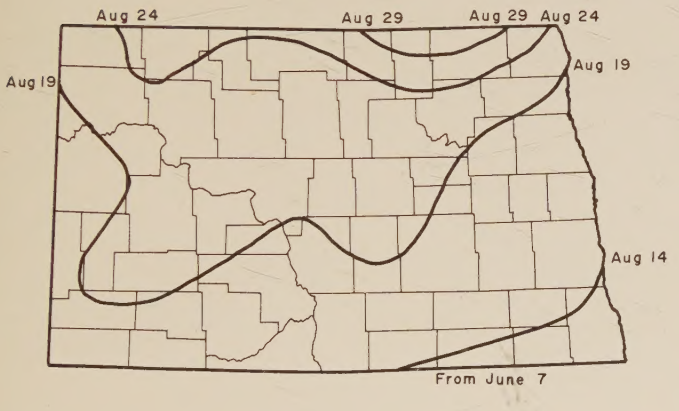
Figure 17. Average date when 2,000 growing degree days (base of 40° F) will have accumulated from selected planting dates.











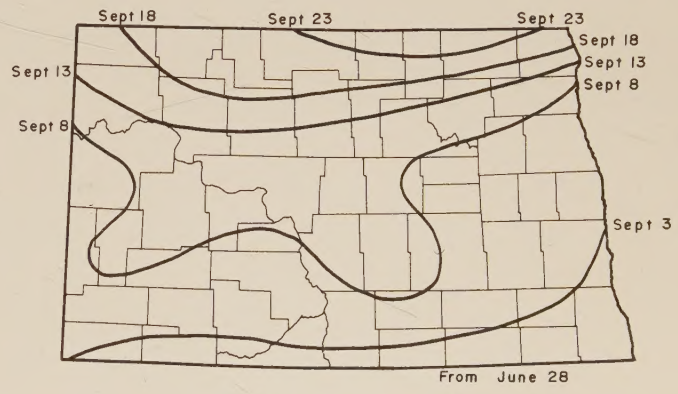


Figure 17. (Continued)

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